G.E.C. Journal

VOL. XVIII APRIL, 1951 No. 2

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THE GENERAL ELECTRIC COMPANY LIMITED
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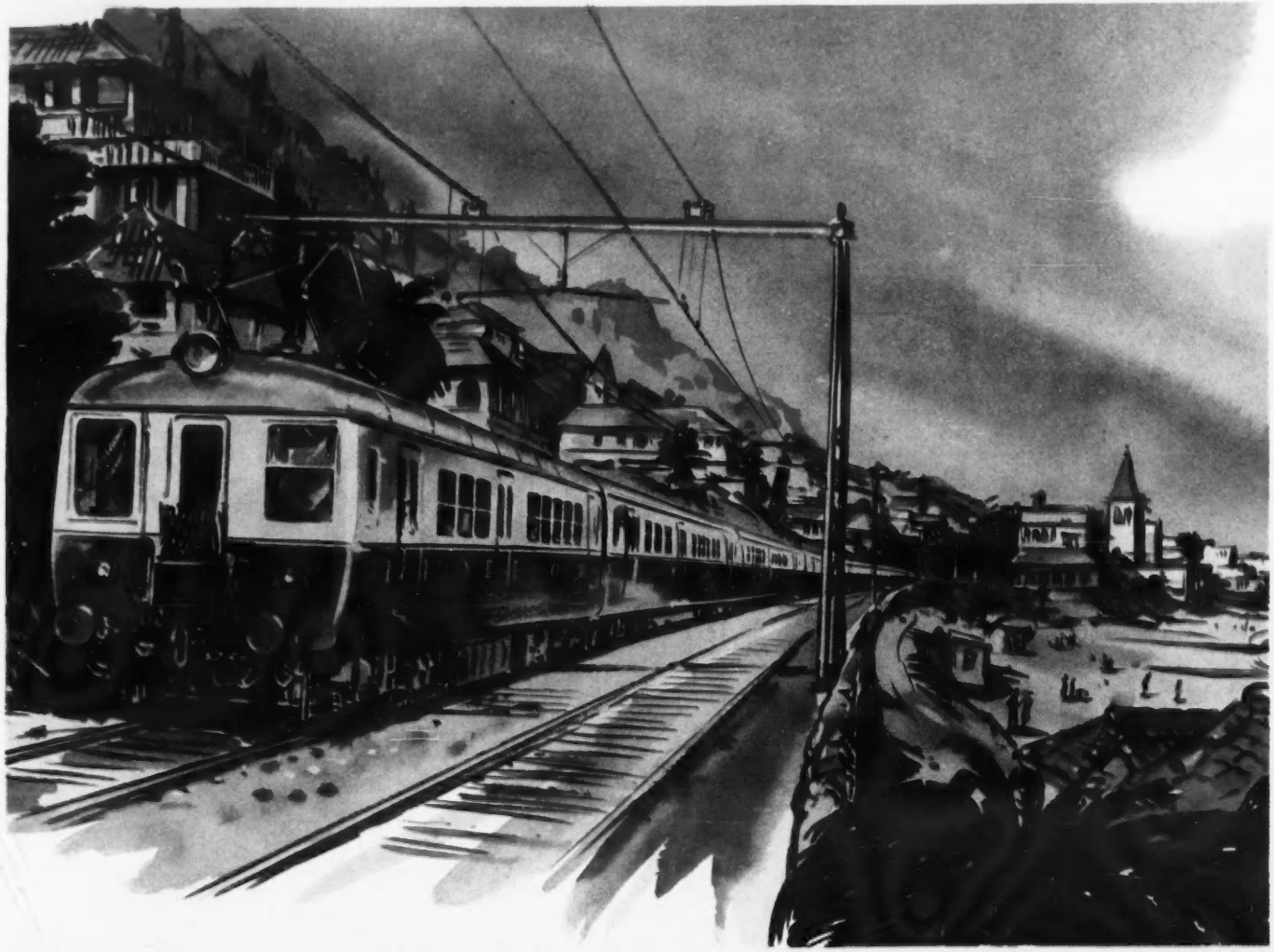


MULTIPLE-UNIT TRAIN ON THE SOCIEDADE ESTORIL RAILWAY, PORTUGAL.

Railway Equipment for Sociedade Estoril, Portugal

By E. H. CROFT, A.M.Inst.C.E., M.I.E.E.
Traction Department, Witton Engineering Works

Early in 1950 *an electric locomotive, together with motor coaches and trailers were put into service on the Sociedade Estoril Railway which serves the popular holiday zone on the Atlantic Coast of Portugal. These are the first electric traction equipments built by a British firm for a Portuguese Railway. Further orders are now in course of execution. A description of the electrical and mechanical gear supplied is given in this article.*

INTRODUCTION.

DURING the early part of 1950, an electric locomotive, two motor coaches and a number of trailers of 5 ft. 6 ins. gauge were put into service on the Estoril Railway in Portugal. These equipments had been ordered from the G.E.C. as main contractors, in order to improve the existing service, and were regarded as a forerunner of further developments on the line. It is interesting therefore to record that the Company has since received an order for nine motor coaches, four driving trailers and one trailer coach. As the equipments represent modern 1,500 volt D.C. practice a technical description will be of interest.

Acknowledgment is made to Dr. Antonio Figueiredo, President of the Railway, and to the Chief Engineer, Señor Bual, for their assistance in the execution of the contract.

As is well known, the Estoril Railway serves an exclusive holiday zone on the Atlantic Coast, which has been renowned for many years for its climate as well as for the natural beauties of the coast line and surrounding country. Apart from its attraction for visitors from abroad, it is also a residential district for many who work in Lisbon and who travel daily to and from the city. It has long been in favour as an ideal spot to which to retire.

The line from Lisbon to Cascais is 25 km., or 16 miles in length (fig. 1), there being eighteen stations in all, excluding the short branch to the stadium. The average station-to-station distance is just under a mile, which indicates the heavy suburban character of the service.

The nature of the country through which the line runs has necessitated many curves and includes a number of steep grades, consequently maximum speeds are somewhat limited, being of the order of 50 m.p.h.

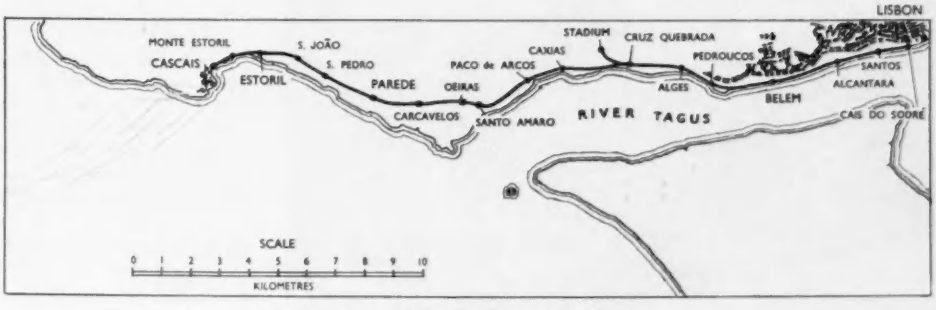


Fig. 1.—Route of the Sociedade Estoril Railway.

The line was originally opened on September 30th, 1889, between Pedroucos and Cascais, and in December of that year extended to Al-Cantara-Mar. Twelve years later it was extended to Cais de Sodre, Lisbon. In 1915 the Companhia dos Caminhos de Ferro Portugueses, concessionaires of the line, called for tenders in order to sublet their concessions on condition that the line be electrified. In 1918 the Sociedade Estoril, having obtained the concessions, took over the management of the line and became responsible for the electrification as well as all other liabilities in connection therewith.

Due to delays caused by the after-effects of the first World War, full electric operation was not begun until December, 1926.

Since then the importance of the line and the benefits derived from electrification have been evidenced by the increase in the number of passengers carried as can be seen from Table 1.

TABLE 1.

Years	Passengers carried
1926	3,710,804
1936	5,162,940
1946	11,641,235
1949	13,207,589

It will be noted that the electrification has resulted in greater traffic and that this trend continues. This alone is ample justification for installing additional electrical equipment.

Fig. 2.—Five-coach multiple unit train.

The management of the railway decided that, as a first step, two motor coaches, five trailers and one locomotive should be added, the last named being required for occasional freight

Fig. 3.—First class passenger accommodation.

trains, and passenger expresses, but mainly as a locomotive for hauling local stopping trains. An examination of the revised time-table shows the very large increase in the number of trains per day made possible by this additional equipment, and indicates that the company provides an adequate modern suburban service.

The varying conditions of service are mostly met by trains consisting of one motor coach and two trailer coaches, or two motor coaches and four trailer coaches. In special circumstances motor coaches are operated without trailers, and at times draw three trailers. Up to the present, driving trailers have not been used extensively, but these are being supplied on a

further order to meet the steadily growing traffic.

MOTOR AND TRAILER COACHES.

MECHANICAL DESIGN.

A train consisting of two motor coaches and three trailer coaches is seen in fig. 2 ; the bodies and mechanical parts were built by Cravens Railway Carriage & Wagon Co. Ltd., Sheffield.

The overall dimensions of both motor and trailer coaches are as below :

Length over buffers	65 ft. 4½ ins.
Width over body	10 ft. 8 ins.
Height overall	12 ft. 5½ ins.
Weight of motor coach (unloaded)	50 tons approx.
Weight of trailer coach (unloaded)	27 tons approx.

The motor coaches are provided with both first and second class accommodation (fig. 3). Seating is available for twenty first class and forty second class passengers, and fifteen tip-up seats are arranged in each of the two end vestibules.

The trailer coaches are non-composite, some being second class and others third class. The second class seating capacity is sixty-five with tip-up seats for thirty-five ; the third class provides seating for seventy-five passengers and for an additional thirty-six on tip-up seats.

All coaches are designed with large vestibules at each end and a transverse central passage way, having hand operated, sliding, double doors at each side of the coach. End doors between coaches are also provided. The motor coaches can be driven from either end.

In every case the coaches are of all-steel welded construction, roof, bodysides and underframe forming an integral load bearing structure. Each coach is carried on two 2-axle swing bolster type bogies, those of the motor coach being of much heavier construction.

First class compartments are panelled in plastic material, while suitable panelling is provided in the other classes. Cork floor tiling is used for the first and second class, and Decolite on all other flooring.

To afford the greatest comfort for the passengers, the whole of the inner surface of the body structure is heat insulated by means of sprayed asbestos, and a continuous air space exists between the inner and outer panelling both of the sides and roof.

LAYOUT OF ELECTRICAL EQUIPMENT.

Some comment on the layout and mounting of the apparatus may be of interest.

There are four main motors of the axle-hung type with solid gears and pinions, two being mounted in each bogie, thus making the best use of the adhesive weight.

As is well known, there has been some difference of opinion as to whether the complicated electrical control and auxiliary equipment of motor coaches should be mounted mainly on the underframe or in an H.T. chamber above floor level. While both methods have been used for many years the one in which practically all the equipment is mounted on the underframe is generally adopted to-day. Obviously such an arrangement allows greater passenger space and such disadvantages as some of the earlier equipments had in the matter of maintenance have been overcome by the improvement in detailed design and, so far as possible, by taking special care to avoid dust entering the various cases.

Each motor coach is provided with two driving positions in the form of small cubicles, which can be completely closed off when not in use. The control couplers are of the fixed end type and are arranged for the usual bifurcation, although this is not essential. The main power equipment is carried in cases on the underframe, as can be seen in fig. 4. Where possible these cases are made dust-tight, but it is obviously not possible to make the case containing the line switches and the associated resistance contactor entirely dust-tight, since, should these operate

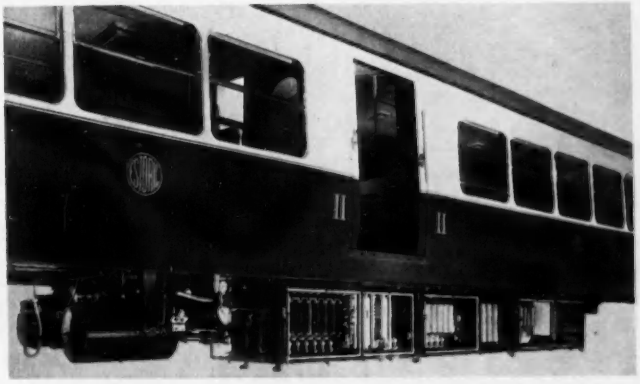


Fig. 4.—Main and auxiliary control equipment cases mounted on the underframe.

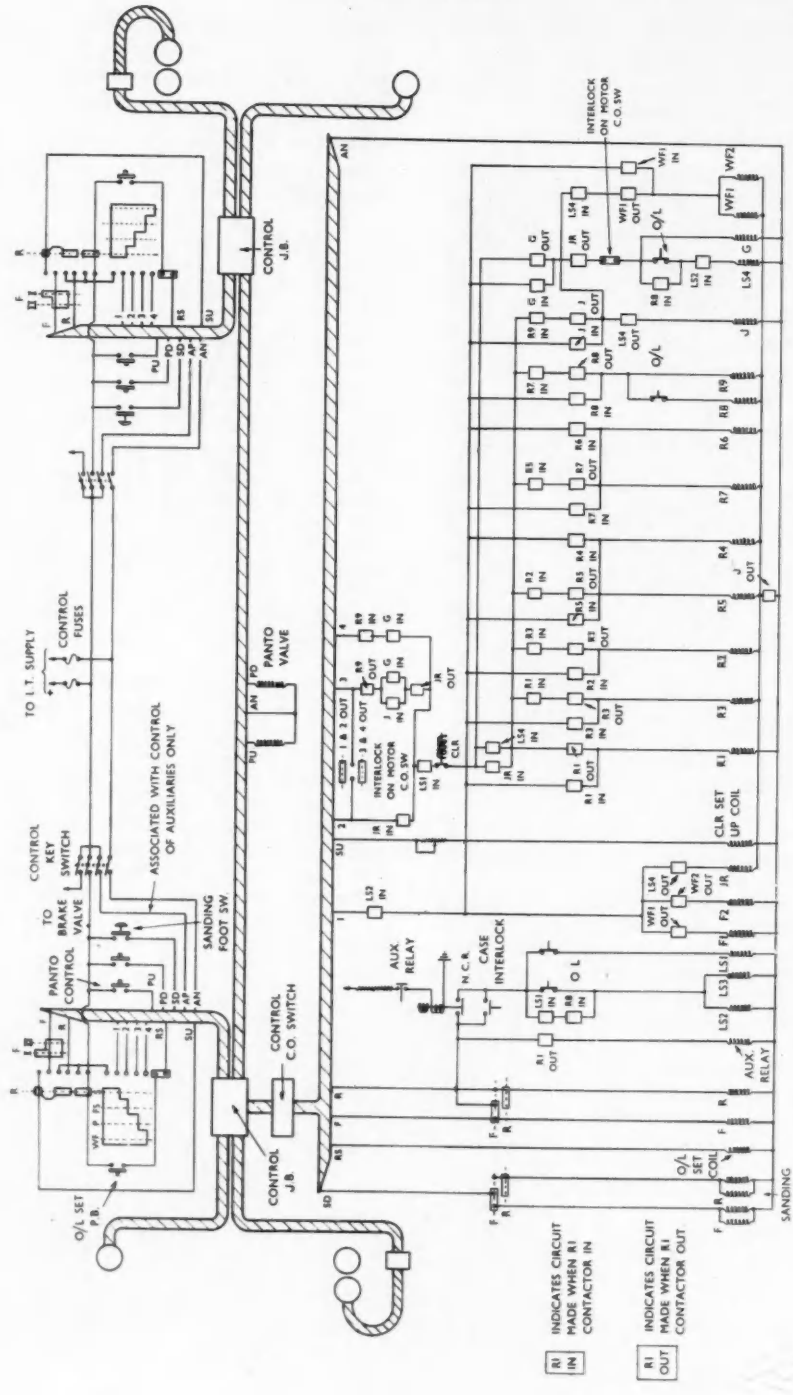


Fig. 5.—Schematic diagram of motor coach control circuits.

on a fault, they must be open to atmosphere so that the arc will clear.

In order to avoid, as far as possible, any danger to the maintenance staff, the covers of these cases can be removed only when the pantograph air supply has been cut off and the pantograph has consequently fallen. The cases contain practically all the auxiliary control equipment except the few switches directly associated with the driving of the train. The main starting resistances are protected against stones being thrown up, but are otherwise entirely open in order to permit the maximum cooling. The three auxiliary machines, namely the motor-generator set, the exhauster and the compressor sets, are all mounted as units on the underframe. In addition, the various air reservoirs with certain associated cocks and reducing valves are also accessible from track level.

It will, therefore, be seen that the bulk of the equipment can be readily inspected and maintained without the use of a pit.

Electrical Equipment.

The motor coaches are driven by four axle-hung motors, each having a continuous rating of 130 h.p., and an hourly rating of 165 h.p. at 750 volts and full field. On tapped field the corresponding ratings are 140 and 170 h.p. respectively ; thus each motor coach has a total continuous rating of 560 h.p. The total weight of each motor including gears and gear cases is 5,100 lbs.

The various circuits required (fig. 6) are formed by the opening or closing of air-operated contactors, the air to which is controlled by solenoid actuated valves energised from the L.T. control and lighting supply, the only exception being the air-operated drum switches and the hand-operated motor cut-out switches.

Power is collected from the overhead line by a modern lightweight single pan pantograph and is fed to the main control equipment through an earthing and isolating switch. The four motors are controlled in two groups of two, permanently connected in series. Thus the motors are designed as 750 volt machines but are insulated for 1,500 volts. The bridge transition from series to parallel is adopted as this arrangement, where it can be used, is far smoother in action than the short circuit transition. The resistance notching, while not being of the multi-notch type for the sake of simplicity, has a sufficient number of steps to ensure smooth and comfortable acceleration.

One step of field weakening is adopted, and is under the driver's control to meet the various service conditions. It will be noted that the field tap system is employed. Overload or fault protection is provided by overload relays associated with the four line switches *LS*1, *LS*2, *LS*3, and *LS*4. If an overload or fault occurs the excess current in either of the two coils *OL* will operate the relay and this will at once open contactors *R*8 and *LS*1, should both these be closed. Thus, apart from a major insulation breakdown adjacent to the pantograph, which is preferably cleared by the substation or track feeder high speed breaker, resistance will always be introduced into the fault circuit before final rupture. The overload relay having operated and the contactors *LS*1 and *R*8 being open, the circuit is finally ruptured by *LS*2, *LS*3, and *LS*4.

This simple and efficient method of dealing with practically all the faults that are liable to

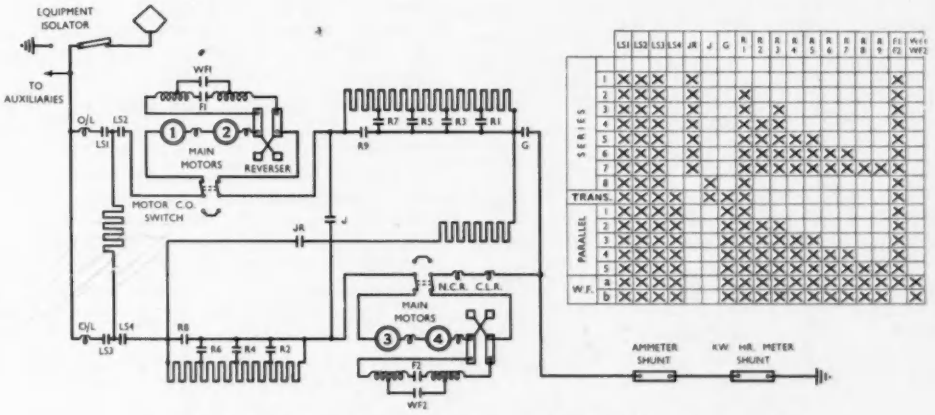


Fig. 6.—Schematic diagram for main power circuit of the motor coach.

Fig. 5.—Schematic diagram of motor coach control circuits.

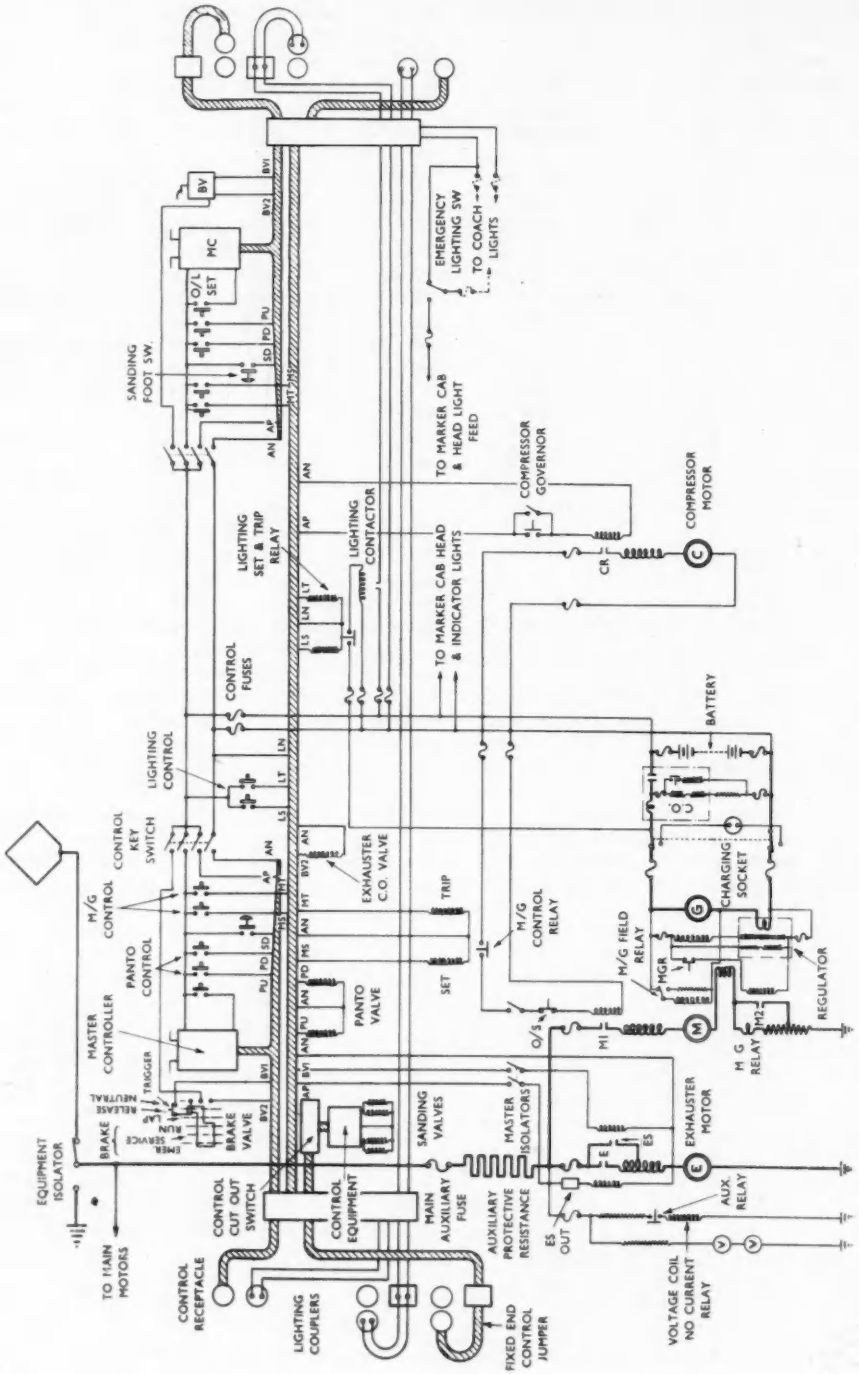


Fig. 7.—Schematic diagram of motor coach auxiliary power circuits.

occur, apart from major faults such as pantograph insulation failure, and the like which are cleared by the feeder breakers, is considered greatly preferable for under-car equipments, and, in varying forms, has been adopted for many high voltage D.C. equipments, including locomotives.

An ammeter and kilowatt-hour meter are arranged to indicate total main power current and energy consumption. A no-volt and no-current system is provided and is described in greater detail below.

Motor Coach Control System.

Control of the power circuits is fully automatic the control current being taken from the L.T. supply at 110 volts, through a key-operated switch. To make a driving position operable, therefore, the driver must close this switch by a special key. There being only one such key to a train it follows that, at any time, only one driving position is operable. The closing of this switch energises the master feed for auxiliary equipment and also the appropriate master controller. Fig. 5 shows the control circuits. The coils corresponding in marking to the contactors, etc., of the main power circuits are the coils of the electro-pneumatic valves, which admit air to the cylinders, the pistons of which close the contactors or operate the reversers. The master controllers are mechanically interlocked to prevent the reverser handle being thrown unless the main handle is in the "off" position. This prevents the reverser being thrown when carrying current. The reverser key can be removed only when the reverser drum is in the mid or neutral position; in this position the main handle is locked off. Thus when the reverser handle is removed the master controller is entirely inoperable. The main handle has four positions, and while the driver remains on the first notch he can handle the coach at slow speed without any automatic progression taking place. By moving to any of the other steps, namely *FS*, *P*, or *WF*, he will automatically accelerate to full series, full parallel, or full parallel weak field respectively, as required. As service conditions demand trains of varying sizes, two settings of the accelerating relay are provided so that accelerations may be maintained reasonably the same on the different trains. To obtain this, two forward positions are provided on the reverser drum, both resulting in forward connection, but the first position gives the lower current setting, and the second a higher current setting. The change to the higher current setting is made by de-energising the set up coil of the current limit relay, thus causing it to arrest progression at a higher series current value. Interlocking follows standard practice. Sequence interlocks ensure correct sequence of closing as the current relay drops and lifts notch by notch; changeover interlocks effect the transfer of the valve coils from the relay circuit to the retaining circuit, and safety interlocks prevent any irregular and dangerous power circuits being formed should an important contactor fail to open. The no-volt relay system, which is a combined no-volt and no-current system, has been adopted due to its superiority over the older systems which were based either on no-voltage or no-current. The relay embodies two windings, one a shunt winding energised from the line, and the other a series winding carrying power current. The contacts are arranged to open the essential line switches, *LS*1, *LS*2, and *LS*3 or permit them to close. Associated with this relay is a simple control voltage relay the contacts of which are in series with the line voltage shunt coil. This auxiliary relay is energised so long as the controller is on, and the first resistance contactor is open. Thus, as soon as the driver throws his controller to an "on" position the auxiliary relay will lift, and, provided line voltage is available, the no-volt coil will lift the relay; then, as soon as the first resistance contactor has closed (and it remains closed throughout series, parallel and weak field connections) the relay is retained by means of its series coil. Thus, except when all resistance is in series with all four motors, the relay will have the quick response of a current type relay, while retaining its initial pure line voltage characteristic.

Motor Coach Auxiliaries.

As in the case of most electric traction equipments, the arrangement of the auxiliaries is of considerable importance from the point of view of general service conditions. Fig. 7 indicates the general arrangement of the auxiliary circuits. The L.T. supply is obtained from a motor-generator set operating in parallel with a lead-acid battery. The motor of this set is a 1,500 volt machine and the generator is regulated at a voltage of 112 by means of a carbon pile voltage regulator. To prevent excessive current in the battery and generator, in the event of the battery being fully discharged in an emergency, the regulator is provided with a series winding so that under such conditions the voltage is temporarily lowered. The usual battery paralleling equipment is introduced, and is, of course, entirely automatic. The H.T. motor is provided with a one-step automatic starting resistance

Fig. 7.—Schematic diagram of motor coach auxiliary power circuits.

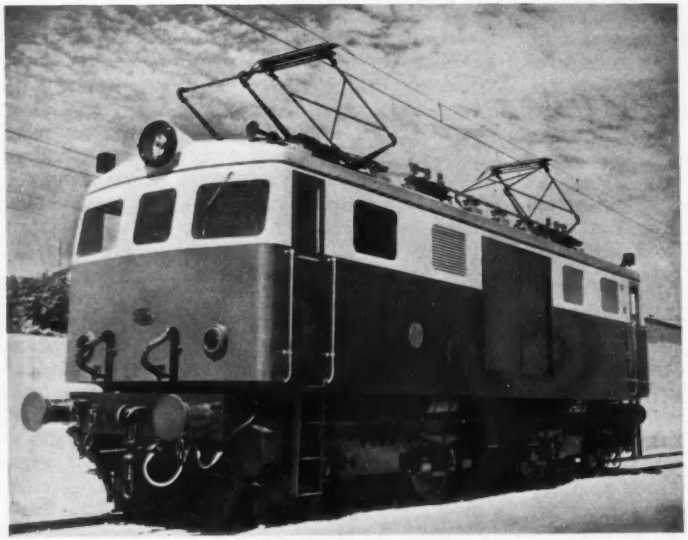


Fig. 8.—1,500 volt locomotive.

and a small section of permanent series resistance.

The trains are equipped with vacuum brakes and the necessary exhauster is driven by a H.T. motor provided with the usual two-speed control, the higher speed being used for quick release of the brakes. This increased speed is obtained by moving the driver's vacuum brake control to the release position, and operating a trigger switch on the handle. The contacts on the brake valve also actuate an exhauster cut-off valve when the driver's valve is in the emergency position, on service application or in lap. Under these conditions the train line is no longer exhausted, thus permitting better regulation and quicker application of the brakes.

The H.T. circuits are protected by a main auxiliary fuse, and a fuse in each parallel feed to the motor generator set, the exhauster, the H.T. circuits associated with the voltage coil of the no-current relay, and the voltmeters. Thus there are always two fuses in series on any fault, and a very high degree of safety is achieved. In order to limit the H.T. short circuit current, the feed to the auxiliary circuits embodies a protective resistance.

The compressed air for the control equipment, pantographs, warning horns and sanding is supplied by a compressor operated by a low tension motor which, when once switched on, is under the control of the compressor governor thereby automatically maintaining the compressed air supply.

Normally the exhauster and the compressor are started up by closing the control key switch.

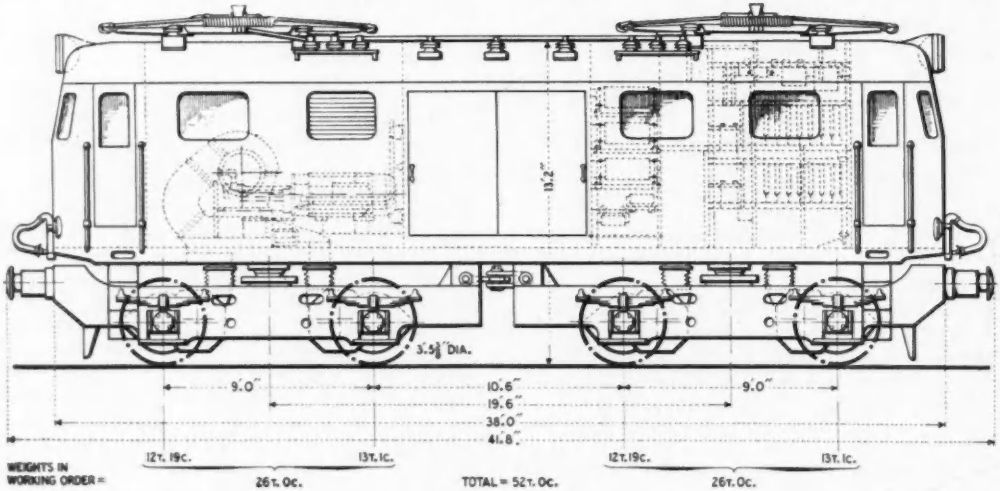


Fig. 9.—General arrangement of the locomotive.

This energises the train line, *AP*, closing the contactors *E* and *CR*, the latter only in the case of the air pressure being below normal.

To avoid the motor-generator sets on a train being shut down while the driver changes from one cab to another, the contactor *M*1 is controlled by a set-and-trip relay. So long as the driver has closed his control key switch he can start or stop all the motor-generator sets on a train.

The pantograph is raised and lowered from any operative driving position by means of two push buttons which operate the pantograph valve, which in turn will admit air to, or release air from, the pantograph thereby raising or lowering it, as required. By this means the pantographs on any number of motor coaches may be controlled from any driving position in which the control switch has been closed.

The sanding of all motor coaches in a train is also controlled electro-pneumatically from a foot switch. Selection of the correct sanding for the direction of motion is carried out automatically by contacts on the main reverser drum. All the lights on the train are fed from the L.T. supply and are controlled by push buttons associated with a simple set-and-trip relay operating the main lighting contactor.

Should it be necessary, an emergency switch may be thrown so that a number of the lights are fed directly from the battery.

LOCOMOTIVE.

General Arrangement.

Before proceeding to consider the machines and apparatus, of which many parts are common to the motor coaches and the locomotive, it will be appropriate to give a brief description of the locomotive, the mechanical portion of which was constructed by the North British Locomotive Co. Ltd., of Glasgow.

As already mentioned, the locomotive, though small, has to meet a considerable range of service conditions. It is required for hauling passenger trains up to 240 tons and goods trains of up to 600 tons, with maximum speeds of 50 miles per hour and 30 miles per hour respectively. Apart from this, it has many lighter duties to perform, including, on occasions, a small amount of shunting.

Careful consideration indicated a bogie locomotive having two 2-axle bogies. To meet the rather high tractive efforts required an articulated bogie was chosen, with the draw gear mounted on the bogies. Fig. 9 shows the general arrangement of the locomotive. It will be seen that the bogies are provided with fore and aft and transverse bearers, the former having the advantage that they reduce the effect of draw gear reaction to a small degree. A further interesting feature about the bogie is the fact that the king pins do not actually carry any vertical load, but function only as a pivotal point for the bogie. They are so arranged that they are transversely sprung to the body. This results in a very much smoother entry to curves or crossovers as the rotational acceleration of the body during a change of direction is cushioned. Although the locomotive is not used for high speeds, tests in service suggest that these various features are of considerable benefit.

The locomotive is provided with a driving position at each end (fig. 10). It is important that particular attention should be paid to the mounting of the controller. In this instance, the controller instead of being of the conventional desk mounted type, which has certain disadvantages, is of the pillar type mounted to the right front of the driver, almost at his side, and allowing ample leg room combined with very easy reach to the handles. Such features are difficult to obtain with the conventional desk mounting. The locomotive is also provided with a central space for carrying luggage (fig. 9).

Towards one end of the locomotive is situated the auxiliary machine compartment containing

Fig. 10.—Driver's cab on the locomotive.

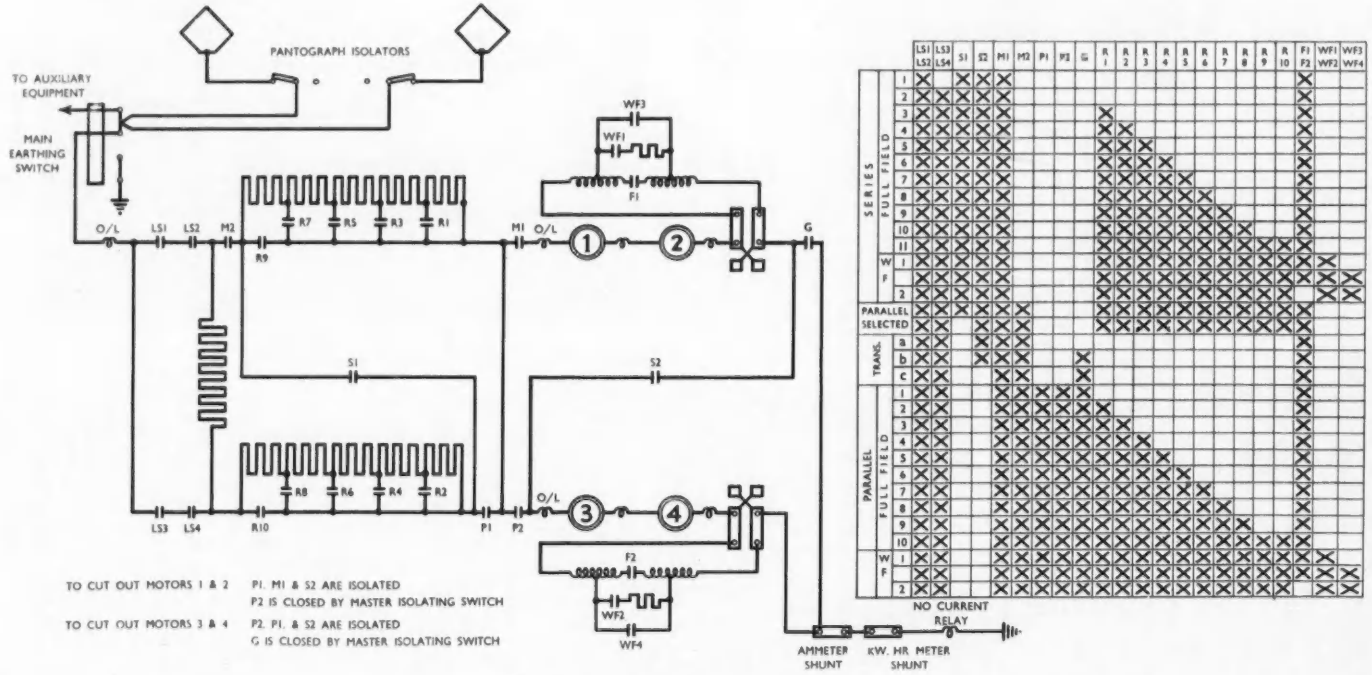


Fig. 11.—Locomotive main power diagram.

the blowers, exhauster, compressor, many of the auxiliaries and the low-tension auxiliary switches and control gear, as distinct from that essential to the driving position. Towards the other end of the locomotive are a resistance compartment and the H.T. chamber in which are housed the contactors, line switches, reversers and so forth for controlling the main motors. The resistances are carried in a separate compartment, specially designed so that the heat cannot reach any other electrical equipment, and are ventilated from the main blower. The H.T. chamber is fully interlocked to prevent entry when any of the equipment is alive.

The roof carries two pantographs each having a suitable isolating switch.

Table 2 gives a general indication of the main data.

Control Equipment.

The power scheme adopted for the locomotives is indicated in fig. 11. In accordance with accepted practice two pantographs are fitted, although one is sufficient for collecting the current. A usual form of earthing switch associated with safety interlocking on the H.T. door is provided in the circuits between the pantographs and the power equipment. It will be noted that the same switch earths the auxiliary equipment.

As the locomotive has to deal with a large variety of loads the usual shunt transition is adopted, since bridge transition is not so suitable for operation at varying loads.

Service conditions demanded a relatively large number of control steps for the locomotive, and to obtain these in a simple way the two sections of resistance are paralleled during parallel combination of the motors. The overload system will be seen to be almost identical with that provided on the motor coaches.

To obtain the top speed required there are two steps of weak field ; it may be noted that the first step is a non-inductive divert resistance across only a portion of the field. By this means the stability of the motor on surge is maintained as a number of the field turns remain unaffected by the divert.

A further advantage of this system is that it permits the final running step to be a simple form of tapped field. This is accomplished by the opening of contactors *F*1 and *F*2 as soon as *WF*3 and *WF*4 contactors have closed.

Auxiliaries.

The auxiliary circuits call for no special comment as they closely resemble those already described for the motor coaches, the conditions of service demanding only slight differences. For example, the control key switch has two "on" positions, one for freight working and one for passenger working. By this means the driver is able to set up the correct functioning of emergency brake conditions should the dead man's equipment operate, it being desir-

TABLE 2.

LOCOMOTIVE: MAIN DATA.

Gauge	1,665 mm.	5 ft. 5 $\frac{3}{16}$ ins.
Length over buffers	12,713 mm.	41 ft. 8½ ins.
Height to roof	4,013 mm.	13 ft. 2 ins.
Maximum width	3,245 mm.	10 ft. 7$\frac{3}{4}$ ins.
Height to centre of buffers	1,050 mm.	3 ft. 5$\frac{3}{4}$ ins.
Wheelbase	8,687 mm.	28 ft. 6 ins.
Wheelbase (bogie)	2,743 mm.	9 ft.
Wheel diameter	1,050 mm.	3 ft. 5$\frac{3}{4}$ ins.
Weight per axle	13·16 tonnes	12 tons 19 cwts.
Tractive effort at 25 per cent adhesion	13,200 kgs.	29,120 lbs.
Maximum speed	80 k.p.h.	50 m.p.h.
Minimum radius of curve	125 m.	6·2 chains
Total weight in working order with 3 tons of baggage	55·9 tonnes	55 tons

able for this to function slightly differently in passenger service from freight service.

The control scheme differs considerably from that of the motor coaches as it does not provide any automatic acceleration. For a locomotive which has to handle a large variety of loads, automatic acceleration is obviously unsuitable.

The master controller is provided not only with the main accelerating handle and a reverse key, but also with a combination handle. If the driver wishes to pass into parallel from series he pre-selects parallel on his combination handle and as soon as he has moved his main handle back sufficiently to introduce the correct amount of starting resistance the transition to parallel takes place automatically. The control of the two weak field positions is arranged on the main handle which permits the driver to use them either in series or parallel combination.

In place of the simple form of dead man's equipment fitted to the motor coach, that on the locomotive consists of dead man's pedals. By having two pedals, one on each side of the driving position, and at the same time having a slight time lag before the dead man's equipment operates after the release of the pedal, the driver can move from one side of the cab to the other while his controller is on. This is a great advantage when backing on to a train and for occasional shunting duties and the like. If he releases pressure from the pedals for more than about five seconds the dead man's equipment operates.

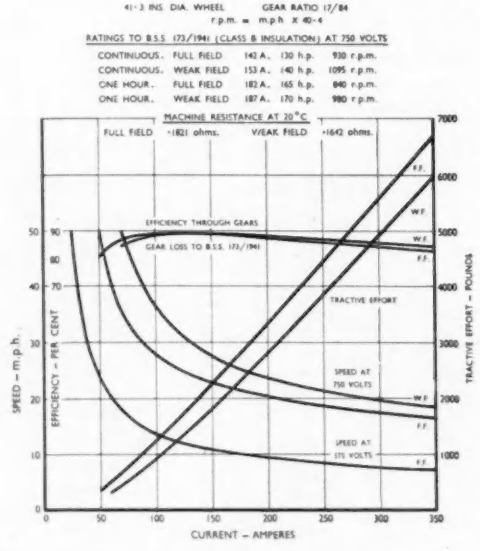
DRIVING MOTORS AND AUXILIARIES.

The difference in the performance demanded by the motor coaches and the locomotive, unfortunately, prevented the use of a single type of motor, but the latest improvements in design and manufacture were embodied in both types.

The characteristics of the motors for the motor coaches and for the locomotive are illustrated in figs. 12 and 13, which also give full data regarding the two machines. The weights of these machines are 5,100 lbs. and 6,940 lbs. respectively, including gears and gearcase.

To meet the wishes of the railway officials, a standard diameter of wheel of 1,050 mm. was adopted, and this results in a slightly heavier machine for the motor coaches than would be necessary were a 36 in. wheel (915 mm.) used. If the latter wheel is used, the motor weight is reduced due to the smaller gear ratio required to give the same performance as with the larger wheel. Fig. 14 shows the general construction and appearance of the locomotive motor, while fig. 15 shows a motor coach bogie with the two motors mounted in it.

The following points regarding design and construction of the motors apply to both types. The wave wound armature is built up on a steel sleeve into which is pressed an alloy steel shaft.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CONTINUOUS. FULL FIELD 142 A. 130 h.p. 930 r.p.m.
CONTINUOUS. WEAK FIELD 153 A. 140 h.p. 1095 r.p.m.
ONE HOUR. FULL FIELD 182 A. 165 h.p. 840 r.p.m.
ONE HOUR. WEAK FIELD 187 A. 170 h.p. 980 r.p.m.
MACHINE RESISTANCE AT 20°C.
FULL FIELD ·1821 ohms. WEAK FIELD ·1642 ohms.
EFFICIENCY THROUGH GEARS
GEAR LOSS TO B.S.S. 173/1941
TRACTIVE EFFORT
SPEED AT 750 VOLTS
SPEED AT 375 VOLTS
F.F.
W.F.
SPEED – m.p.h.
EFFICIENCY – PER CENT
TRACTIVE EFFORT – POUNDS
CURRENT – AMPERES

Fig. 12.—Motor coach motor performance at 750 and 375 volts.

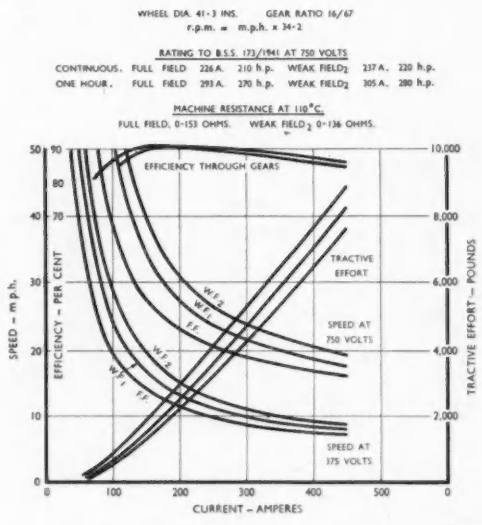
WHEEL DIA. 41·3 INS. GEAR RATIO 16/67
r.p.m. = m.p.h. x 34·2
RATING TO B.S.S. 173/1941 AT 750 VOLTS
CONTINUOUS. FULL FIELD 226 A. 210 h.p. WEAK FIELD2 237 A. 220 h.p.
ONE HOUR. FULL FIELD 293 A. 270 h.p. WEAK FIELD2 305 A. 280 h.p.
MACHINE RESISTANCE AT 110°C.
FULL FIELD, 0·153 OHMS. WEAK FIELD2 0·136 OHMS.
EFFICIENCY THROUGH GEARS
TRACTIVE EFFORT
SPEED AT 750 VOLTS
SPEED AT 375 VOLTS
W.F.2
W.F.1
F.F.
SPEED – m.p.h.
EFFICIENCY – PER CENT
TRACTIVE EFFORT – POUNDS
CURRENT – AMPERES

Fig. 13.—Locomotive motor performance at 750 volts.

It is carried on roller bearings, the one at the commutator end being a double-lipped location bearing. The bearing housings are arranged so as to be removable with the armature and, consequently, bearings need only be exposed when they require attention. Particular care is taken during manufacture to obtain a solid armature winding. The slot portions of the coils are insulated with a micanite wrap which is pressed to exact size. This gives a hard covering to the coil which does not require any external taping and consequently contains the highest possible percentage of mica. The interturn insulation on the end windings consists of glass and mica tape, while micanite sheets are used for the insulation to earth and between layers. The spaces formed between the end windings are filled with a special insulating cement and the armature is banded while hot, sufficient tension being applied to bring the coils down solidly on to their supports. Particular attention is paid to the banding process and the band wire tension.

The field coils are wound with copper strip and are impregnated during winding with a synthetic resin varnish which is finally polymerised under heat and pressure. This type of coil is superior in mechanical and electrical properties since the copper and the class "B" insulation are virtually bonded together as a solid mass.

The brush gear is of an exceptionally rigid type supported from the end of the motor frame. The insulation is of moulded micanite covered by porcelain bushes which provide an easily cleaned creepage surface. Brush springs are of the clock spring type and adjustable. Copper braid flexibles connected to the contact tip on the brush spring are used, these being considered greatly superior to pig tails. The suspension bearings are of the sleeve type, lubricated by wool packing. The brasses are retained by axle caps with large location surfaces and utilising through bolts. The drive is by means of Wiseman single reduction spur gearing enclosed in a fabricated gear case. Oil being used for lubrication, great care is taken in the construction to avoid leakage.

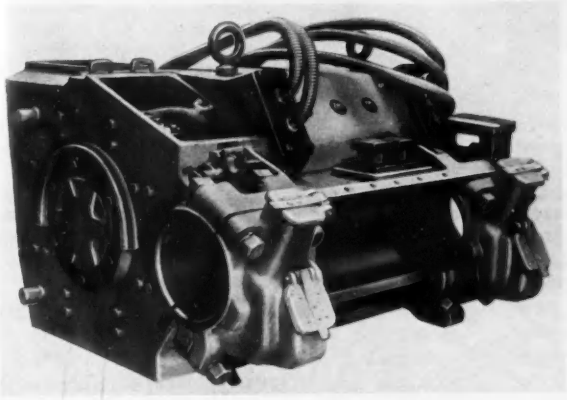

Fig. 14.—One of the four axle-hung traction motors.

In the interests of standardisation the motor-generator set providing the low-tension supply is the same both for the motor coaches and the locomotive. The output is 8 kW at 110 volts. The method of construction conforms with standard traction practice and is closely similar to that of the main motors. The H.T. motor and the L.T. generator are contained in the same frame. The H.T. motor is a 2-pole compound wound machine with the shunt fields

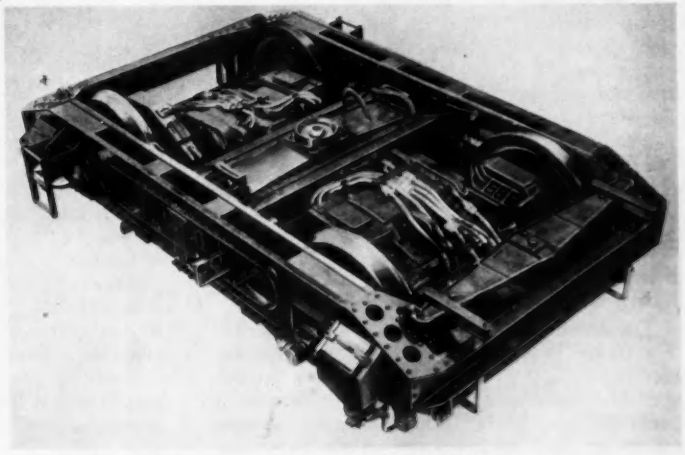

Fig. 15.—Motor bogie with two 170 h.p. axle-hung traction motors.

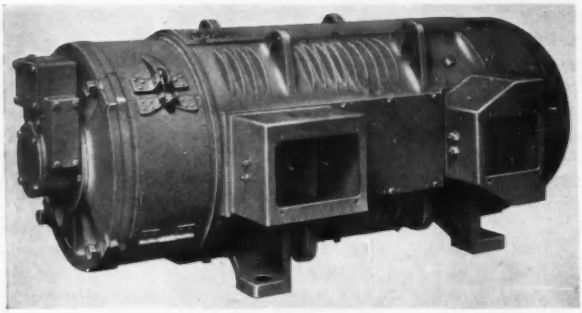

Fig. 16.—Motor-generator set.

fed from the 110 volt supply ; the generator is a 4-pole machine, but is not provided with interpoles. A carbon pile voltage regulator maintains a constant voltage over very large variations of load and line voltage. The regulator has a degree of decompounding so that the voltage is slightly lowered in the event of the battery being discharged. For safety, a simple form of centrifugal overspeed device is fitted which cuts off the power supply to the H.T. motor in the event of an overspeed. In the case of the motor coaches the set is carried on resilient mountings and underslung ; in the locomotive it is mounted on a heavy section bedplate rigidly bolted to the frame. The set is of the totally enclosed type in which the cooling air passes through ducts in the shell of the machine ; the total weight is 2,230 lbs. The machines have been designed and tested to ensure their ability to withstand, without flashover, the short circuit across the H.T. motor which is formed by the traction motors on interruption of the power supply. The general construction of the set is shown in fig. 16.

The high tension motors used for the exhauster call for no special comment. They, too, are of the traction type and embody similar features to those mentioned for the main motors and the motor-generator set.

CONTROL COMPONENTS.

PANTOGRAPH.

The design of pantograph is shown in fig. 17. The frame is of lightweight tubular construction carrying a single pan which is sprung to the apex of the pantograph and which, by the use of two light torque bars across the apex, always moves up and down parallel to the mounting plane of the pantograph. This involved some slight complication in the design, but was adopted in order to prevent tilting of the pan which was possible when each end was separately sprung to the pantograph and which had the effect of reducing clearance. Ample clearance is a very desirable feature on any railway, but is particularly important on a line where bridges or tunnels have very tight clearances.

Most joints on the pantograph are provided with ball bearings in order to reduce friction to a minimum ; the bearings are shunted by means of copper flexibles. The pan is provided with the usual copper strips which have a small lip projecting over the steel part of the pan.

The pantograph is raised by air pressure but when once lifted is maintained in position by means of the two springs seen in fig. 17. In order to avoid violent collapse of the pantograph on to the roof when the air is released, a damping choke is fitted in the cylinder exhaust. The same design of pantograph is used both for the locomotive and the motor coaches.

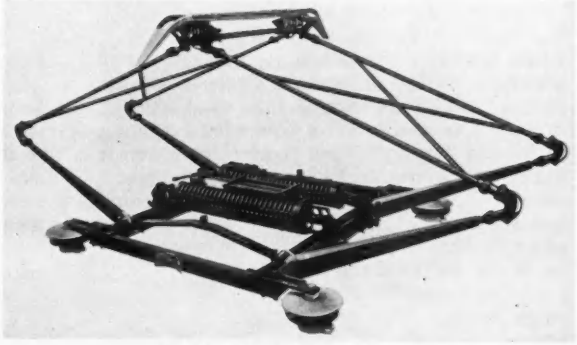

Fig. 17.—Single pan pantograph.

Fig. 18 illustrates the main earthing switch used on the locomotive for safety earthing and for the interlocking of the H.T. chamber. This switch, in part, follows standard practice, inasmuch as it is essential to operate the lock on the right hand side by means of the reverser key before the main handle on the left can be moved to the earthed position and permit the H.T. chamber to be entered. The action of unlocking releases the air pressure supporting the pantograph which, however, will not fall instantaneously, so that if the main handle were thrown very rapidly to the earthed position, damage might result. To surmount this difficulty a

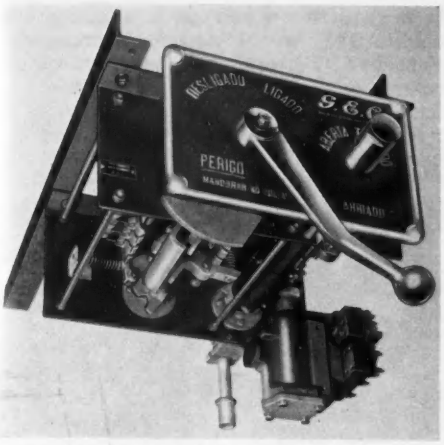

Fig. 18.—Locomotive earthing switch.

number of devices have been employed such as an additional intermediary lock which forces the operator to take the reverse key from the first lock, place it in the second lock and unlock it before operating the main handle. In the present instance an air cylinder is provided in association with the pantograph cylinder, and, regardless of the position of the lock on the right-hand side, the main handle cannot be moved to earth until air has been released from the pantograph. When the air pressure in the pantograph falls well below that at which the pantograph will drop, the cylinder on the isolating switch operates and permits the isolator to be earthed.

Main and Auxiliary Contactors.

As already mentioned, the main circuits are controlled by means of air-operated contactors, the same design of contactor (figs. 19 and 20) being used both for the motor coaches and the locomotive. The contactor is built up on mild steel bars with bakelite insulation, very adequate creepage distances being provided. At the bottom of these bars is carried the air cylinder operating the main contacts; in front of the cylinder is the electro-pneumatic valve, while at the back are the auxiliary contacts. The contactor is provided with a suitable knuckle action.

The top of the bars carries the blow-out unit with associated blow-out plates. Figs. 19 and 20 show the contactor with the arc chute, removed and in position respectively. It should be noted that the arc chute plates, or pole plates, may be swung up and latched for inspecting the contactor and that a very simple and effective anti-blowback screen is provided under the lower arc horn. Although unnecessary in ordinary circumstances, in an emergency this screen

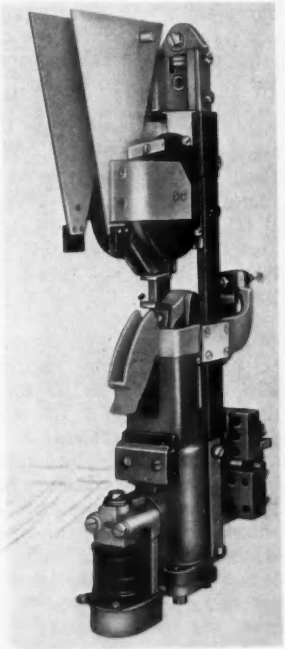

Fig. 19.—Main contactor with arc chute removed.

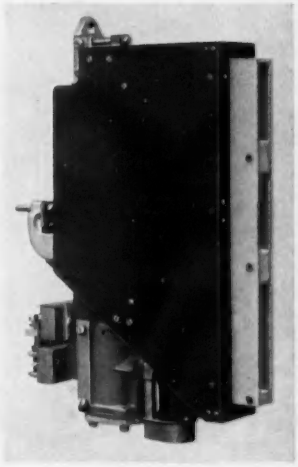

Fig. 20.—Main contactor with line switch type arc chute.

increases the capacity of the contactor considerably. It will also be noted that the arc chute is composed of an inner and outer chute, the inner one, seen projecting to the front, being the arc chute proper which is manufactured from a form of asbestos sheet ; the outer one is used both as an electrical insulating screen and as a mechanical stiffener. For the contactors acting as line switches a slightly larger arc chute is fitted, and, in the motor coaches, in which the contactors are mounted in cases, those carrying out line switch duty have relatively free access to the atmosphere.

Resistances, Relays and Interlocks.

The main resistances used both for the motor coaches and the locomotive are of the cast-iron type utilising mica and micanite insulation for the primary insulation and porcelain for the secondary insulation. The conditions of service are such that the high heat capacity of the cast-iron type of resistance is of considerable benefit. This, however, is not always the case. The high-tension auxiliaries require 1,500 volt contactors of a small and relatively simple type. Fig. 21 is typical of all electric contactors used for this purpose. It will be seen that, apart from the fact that it is much smaller than the main contactor and that it is operated by means of a solenoid and a lever type armature, the general construction is very similar to the main contactor. Space does not permit descriptions of, or reference to, all the relays that are used. In general they are of essentially simple construc-

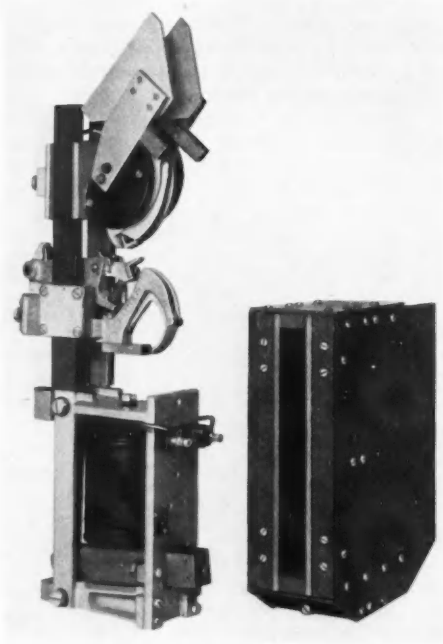

Fig. 21.—Auxiliary H.T. contactor.

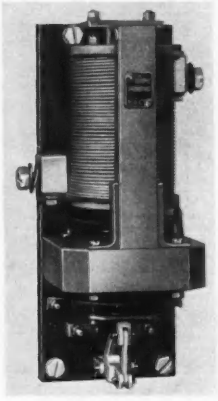

Fig. 22.—Reverse current relay.

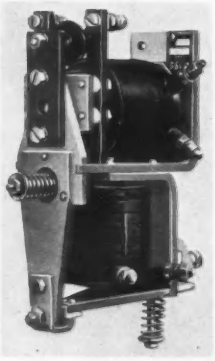

Fig. 23.—Set-and-trip relay.

tion employing mild steel pressings or simple mild steel parts, the exception being the polarised relay used for paralleling the battery and the generator for which a magnetic field circuit of laminated iron is employed. Fig. 22 and 23 illustrate two typical relays. One shows the polarised relay already mentioned. It is of the truly polarised type, inasmuch as it carries a form of armature operating in a field, and does not depend on the more common practice of counter series turns which are often used for battery paralleling relays, and which, in certain circumstances, can cause considerable trouble. Fig. 23 shows one of the set-and-trip relays consisting of two solenoids with their associated pressed steel magnetic circuits and a form of rocking main armature. If the top coil be energised the upper portion of the main armature is pulled towards the solenoid and the disc contacts are made. The disc can just be seen at the top. As soon as the armature has moved to this position the armature associated with the lower coil drops down under the influence of gravity and the spring, and holds the main armature in the closed position by engaging a suitable projection on it. As soon as the lower coil is energised the lower armature will lift and disengage the stop on the main armature allowing this to open. This relay is used for the

ain lighting control and also for the control the motor-generator set on the motor coaches. Fig. 24 shows one of the control receptacles d jumper plugs.

ASTER CONTROLLER.

The master controller for the motor coaches lls for no special comment. It is provided ith the usual simple form of dead man's button

Fig. 24.—Control couplers.

associated with such coaches. The master controller for the locomotive is of a somewhat unusual type. In the past, as already mentioned, the locomotive master controller has been mounted in a desk more or less in front of the driver. It has long been realised that this was far from ideal for a driver who was seated and, therefore, this new design of controller is primarily based on the most suitable operation for a driver in a sitting position. Accordingly, it was decided that the right place for the controller was at the driver's side rather than in front of him ; the general idea being that he should sit between his master controller and his brake controller, the two being arranged one on each side and slightly forward of his body. From fig. 25 in which the top cap of the master controller can be seen, it will be observed that it stands as a sort of pillar on the right of the driver so that all the handles are within easy reach. The small handle shown in the form of a key at the top left-hand side of fig. 25 is the control switch key which he removes when he leaves the locomotive and which has already been mentioned. It has two positions, in the one it sets up the emergency brake equipment in a manner suitable for freight trains, and in the other in a manner suitable for passenger trains.

The top right handle in fig. 25 is the reverser and combination handle. This is also in the form of a removable key and should be removed when the driver changes from one cab to another. When taken out in the neutral position it makes the whole controller dead in the same way that when the control switch key is removed it makes it or its associated circuits dead and permits driving from another position. The main handle controlling the resistance starting and the field weakening appears as the large lower handle in fig. 25 and is provided with a step-by-step device. It is of completely modern design utilising a very well proven type of finger which is self-aligning.

In conclusion it may be said that these equipments have now been operating for about a year and have been giving every satisfaction. The amount of adjustment required has been virtually negligible and the locomotive was running in service almost from the moment it arrived on site.

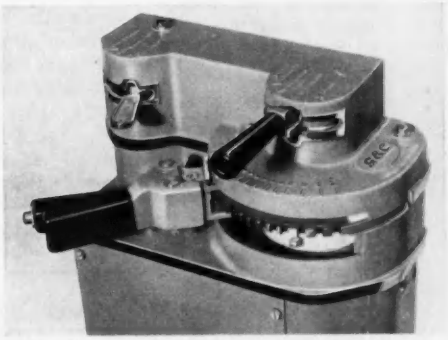

Fig. 25.—The locomotive master controller.

Colour and Lighting

(Part 2)

OBJECTIVE AND SUBJECTIVE CORRELATIONS AND CHOICE OF ILLUMINANTS

By G. T. WINCH, M.I.E.E., F.Inst.P., F.I.E.S. and BRENDA M. YOUNG, B.Sc.

G.E.C. Research Laboratories.

The original work described in this paper follows on that in the earlier publication "Colour and Lighting" in Vol. XVI, No. 4 of this Journal, October, 1949.

Brief reference is made to the history of the subjective choice of desirable colour-rendering properties of illuminants, particularly tubular fluorescent lamps. This is followed by a description of binocular viewing techniques and new binocular viewing apparatus which has been developed. Preliminary results are given of objective chromaticity measurements of the subjective chromaticity shifts of coloured samples tested in this apparatus. Suggestions are made for utilising the same apparatus to determine the suitability of decoration materials and colour schemes.

(1) INTRODUCTION.

IN a previous issue of this Journal,[1] one of the present authors outlined the colour problems confronting the lamp manufacturer and lighting engineer. These were stated in brief as :

(*i*) "The choice of the minimum number of 'colours' of lamps to be manufactured which will provide acceptable colour-rendering in the main classes of lighting application.

(*ii*) "The control in manufacture of the colour and colour-rendering properties of the lamp to ensure uniformity in these characteristics to the necessary accuracy.

(*iii*) "The design of lighting installations incorporating these lamps, which will be acceptable to the user in providing an appropriate level of illumination and colour-rendering suited to the application, thus contributing towards the overall aesthetic effect."

In the article already referred to it was shown that, in general, the aspects of this problem involving objective colour measurements had already been investigated at some length and very considerable progress made in the techniques of objective measurements of colour and colour-rendering properties. The concluding sections 8 and 9 of that paper referred to the outstanding problems still requiring investigation, namely the correlation of subjective and objective colours and subjective colour preference.

The aim of the present paper is to describe the recent work which has been carried out in an endeavour to correlate objective measurements of colour and colour-rendering properties with the subjective appreciation of colours.

(2) EARLY SUBJECTIVE TECHNIQUES IN COLOUR - RENDERING DETERMINATIONS.

About 1936-37, during the early stages of the development of fluorescent lamps, it was required to choose from the available experimental lamp "colours", those which would be most suitable for certain market applications. At that time an attempt was made to determine this choice, using the following techniques.

A series of five viewing cabinets about 3 ft. cube were arranged adjacent to one another at table level, and on the floor of these viewing cabinets was mounted a number of strips of coloured material running the length of the five cabinets. The walls of the cabinets were white and in the top of the cabinets were mounted, respectively, the various light sources to be compared, namely tungsten lamps, artificial daylight produced by tungsten lamps and blue

ilters, and three different "colours" of fluores-ent lamps. Between each light source and its espective cabinet was a sheet of diffusing naterial arranged so that the form of light ource could not be seen by the observer. The onts of all the cabinets were closed with lack curtains. The illumination level on the oor of all the cabinets was adjusted to be sen-ibly the same. A group of observers commented n turn on the colour-rendering properties of he light sources by reference to the appearance of the multi-colour materials common to all cabinets, and also by the appearance of the more common foods and drinks which were also arranged on the floor of the cabinets. Before making their judgments the observers were conditioned in a semi-dark room for about a quarter of an hour. After conditioning, each observer was asked to look in one cabinet selected at random and to give his comments on the colour-rendering properties. The results of these measurements were inconclusive and, therefore, the observers were subsequently allowed to compare adjacent cabinets simultaneously. With this latter form of viewing, moderately consistent results were obtained. It was subsequently found, however, that the orders of preference were dependent on the order in which the cabinets were compared, so that the results from this second method were considered rather inconclusive, except, perhaps, the judgments which were made when comparing any two particular light sources.

It is interesting to note that two of the authors' colleagues, W. R. Stevens and J. M. Waldram, carried out in 1949 a somewhat similar series of tests in cubicles, using a large group of observers and various types of conditioning and viewing, the latter observations being made both simultaneously and sequentially. The results indicated that, for the objects tested, observers who were fully adapted to the light were indifferent to the colour-rendering for all but extreme colours, thus confirming in general the earlier experiments in 1936-37.

The early work in 1936-37, referred to above, had indicated that by direct comparison of two sources, observers were able to give some indication of the relative merits of any two light sources. Consequently, the authors and many other workers in this sphere have since used a simple form of subjective colour comparator for determining qualitatively the relative colour-rendering properties of fluorescent lamps of different "colours". The simple form of comparator used for this latter purpose comprises a table divided in the centre along its length by a vertical board painted black, together with lamp holding arrangements about 3 ft. above the table so that one light source can be operated on one side of the dividing board and the other light source on the other side. Arranged across the

TABLE 1.

BRITISH COLOUR COUNCIL NUMBERS AND COLOUR NAMES OF MATERIALS USED IN THESE EXPERIMENTS.

Nominal British Colour Council Number.	Colour Name.	Remarks.
B.C.C.214	Spectrum Violet	Better match with B.C.C.179—Violet.
B.C.C.100	Spectrum Green	Better match with B.C.C.23—Malachite Green.
B.C.C.185	Cherry	Good match with B.C.C. sample.
B.C.C.57	Spectrum Orange	Good match with B.C.C. sample.
B.C.C.123	Peacock Green	Better match with B.C.C.203—Dioptase.
B.C.C.86	Spectrum Blue	Better match with B.C.C.196—Larkspur.
B.C.C.199	Fuchsia	Better match with B.C.C.200—Beetroot.
B.C.C.52	Lemon	Good match with B.C.C. sample.

TABLE 2.

CHROMATICITY CO-ORDINATES OF SAMPLES MEASURED WITH PHYSICAL EYE COLORIMETER (LIGHT INCIDENT ON SAMPLE AT 45° to NORMAL.)

B.C.C. Colour Name of Sample.	B.C.C. No.	Measured Luminance Factor with Std. Illum. B	Chromaticity Co-ordinates of Samples illuminated by													
			Std. Illum. A 2,850 degs. K.		Simulated Std. Illum. B Approx. 4,500 degs. K.		Simulated Std. Illum. C Approx. 6,500 degs. K.		80 w. Colour Matching MCF/U		80 w. Daylight MCF/U		80 w. Natural MCF/U		80 w. Mellow MCF/U	
			x	y	x	y	x	y	x	y	x	y	x	y	x	y
Spectrum Violet	214	4·8%	·437	·294	·303	·212	·265	·179	·253	·160	·295	·210	·314	·208	·408	·238
Spectrum Green	100	13·1%	·331	·508	·276	·472	·253	·447	·252	·458	·305	·516	·289	·510	·381	·497
Cherry	185	9·5%	·657	·327	·622	·322	·589	·318	·586	·322	·595	·348	·602	·338	·638	·334
Spectrum Orange	57	29·5%	·597	·384	·569	·382	·547	·382	·535	·381	·544	·410	·551	·402	·591	·387
Peacock Green	123	10·1%	·263	·430	·208	·370	·187	·342	·193	·350	·247	·386	·246	·378	·309	·425
Spectrum Blue	86	9·5%	·299	·338	·216	·235	·199	·197	·207	·197	·254	·239	·247	·222	·314	·261
Fuchsia	199	5·6%	·586	·310	·490	·245	·395	·228	·390	·224	·412	·262	·427	·276	·556	·296
Lemon	52	6·8%	·518	·449	·467	·462	·453	·463	·436	·467	·466	·483	·478	·471	·535	·442
White Paper	—	76·0%	·452	·406	·354	·361	·316	·330	·311	·324	·374	·376	·379	·362	·462	·381

ible are strips of a number of different coloured materials.

Coloured fabrics viewed in this way do not form a very good test for acceptable colour-rendering properties, however, for their colours are in any case arbitrary. Any difference in spectral energy distribution may cause their appearance to change, but there is no means of appraising the change. This test is valid for testing a colour *matching* lamp, but not the lamps used in interiors. Complaints of poor colour-rendering occur with objects which are very familiar, such as food or personal appearance, and this simple form of comparator is therefore also used for comparing the appearance of the complexion, foods and other coloured articles.

With a view to reducing the variables in the visual judgments of colour-rendering properties by this method, three British lamp makers agreed in 1945 to use the same series of coloured materials. These were prepared from one batch of mercerised cotton sateen which was dyed in sections, nominally to the British Colour Council colours as detailed in Table 1.

The subjective colour comparator method referred to above, while having proved extremely useful through the years, suffers from the limitation that only qualitative estimates can be made of the relative colour-rendering properties of light sources. With the development of many new powders from which fluorescent lamps can be made, having various colours and colour-rendering properties, a quantitative measure of the subjective colour-rendering properties is becoming increasingly desirable. It was for this reason that the work described in the following sections of this paper was undertaken.

(3) COLOUR SAMPLES: OBJECTIVE MEASUREMENTS.

In order to link the earlier subjective qualita-

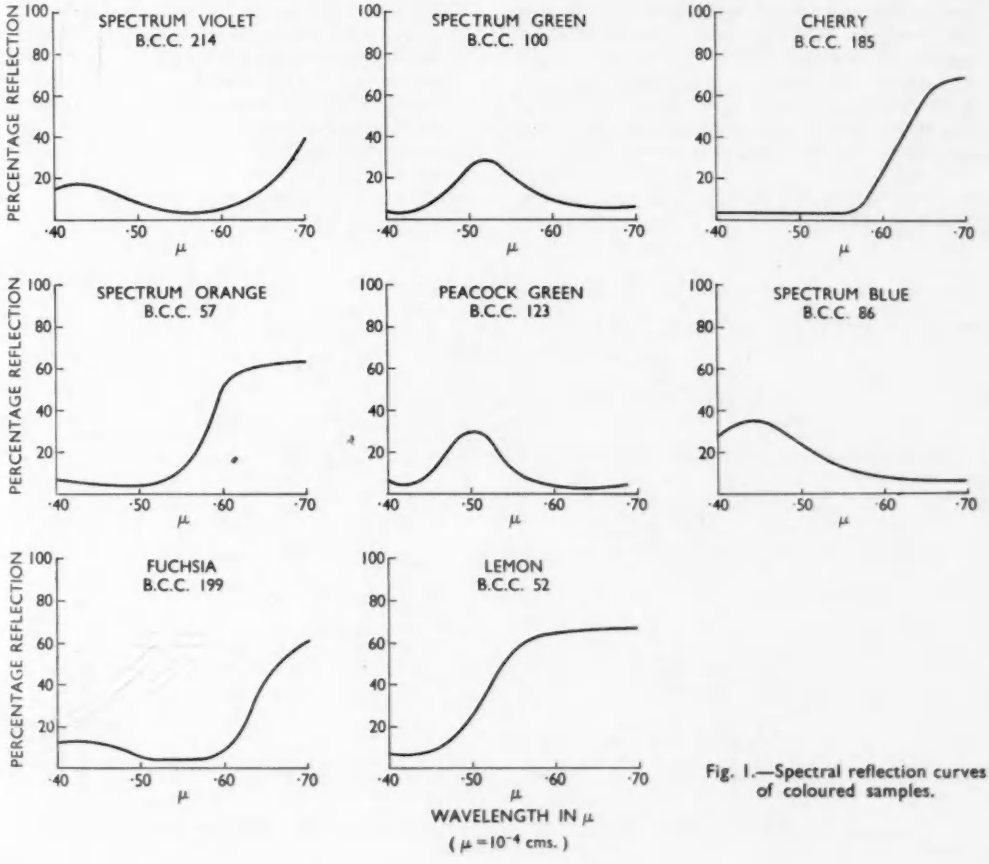

Fig. 1.—Spectral reflection curves of coloured samples.

White Paper | — | 76·0% | ·452 | ·406 | ·354 | ·361 | ·316 | ·330 | ·311 | ·324 | ·374 | ·376 | ·379 | ·362 | ·462 | ·381

tive assessments of colour-rendering properties with the objective-subjective relationships which form the main subject of the present paper, the coloured materials detailed in Table 1 were measured for their chromaticity co-ordinates and luminance factor, using the Physical Eye Colorimeter and Spectrophotometer described earlier by one of the authors.[2] These objective chromaticity measurements were made with the samples illuminated in turn by standard illuminants *A*, *B* and *C*, and also by a range of "white" fluorescent lamps, namely Colour Matching, Daylight, Natural and Mellow. The light was incident on the specimen at 45° to the normal, the measurement being made in a direction normal to the specimen.

The results of these measurements are summarised in Table 2, in which is included also the luminance factor of all the samples. It should be noted that for some patterns there are discrepancies between the chromaticity co-ordinates published by the British Colour Council and the measured values of the samples used. This is also evident from visual inspection of the samples as compared with the B.C.C. colour dictionary, but these discrepancies do not affect the conclusions drawn from this work. The spectral reflection curves for these coloured samples are given in fig. 1.

In fig. 2, the chromaticity values for the specimens are shown plotted in the C.I.E. chromaticity diagram and the letter associated with each plotted point indicates the illuminant. This diagram indicates the shifts of the chromaticity points of the coloured specimens under the different illuminants. It will be remembered that this diagram is not a uniform chromaticity diagram and the extent of the non-uniformity has been indicated by Judd[3] and MacAdam[4] and was shown in fig. 9 of the earlier paper by one of the authors[1] to which reference has already been made. The plotted points in fig. 2 give an indication of the colour-rendering properties of the various illuminants under the defined conditions of view appropriate to the C.I.E. Standard Observer, namely with a small 2° photometer field at high luminance levels.

The objective chromaticity shifts shown in fig. 2 are directly related to the spectral energy distribution of the light sources and it is for this reason that colour-rendering is specified in the C.I.E. system by reference to percentage luminance in the eight agreed spectral bands.[5] The spectral luminance values in the eight bands, of the actual lamps measured, are detailed in Table 3. These data do not indicate how the colours of objects and materials will be rendered under other viewing conditions, for example

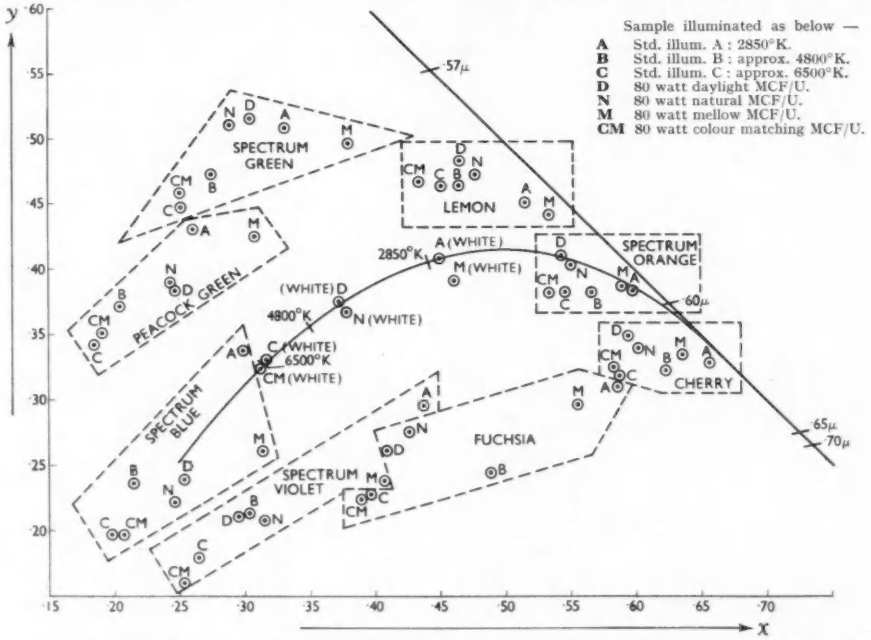

Fig. 2.—Chromaticity diagram showing C.I.E. chromaticity co-ordinates of samples under various illuminants.

with larger fields of view and with simultaneous colour contrast, or when the eye is conditioned either before or during the observations. The next section deals with investigations made in an attempt to co-ordinate these data with subjective colour appreciation under various conditions of view.

(4) BINOCULAR VIEWING APPARATUS AND TECHNIQUE.

Wright[6] has described a visual binocular colorimeter, and similar apparatus was later used by Hunt[7] and others. In these binocular colorimeters one eye of an observer views one half of a photometric field and the other eye the other half, fixation spots being arranged to ensure that when viewed simultaneously the two fields appear juxtaposed. By this means Wright,[8] Hunt,[7] and MacAdam[9] have been able to assess quantitatively the extent to which the colour of materials or the light in a photometer field appears to change with different conditioning of the eye prior to and/or during the observation. To quote one example, Hunt has shown, and, in the earlier paper,[1] one of the authors also demonstrated, that with the light adapted eye an illuminated colour sample appears more saturated than with a dark adapted eye. For this reason spectral colours appear to the light adapted eye, as compared with the dark adapted eye, to be supersaturated so that when plotted on a chromaticity diagram, the spectral colours lie outside the spectral locus determined under dark adaptation.

On June 8th, 1950, at a Conversazione at the Imperial College of Science, a simpler form of binocular viewing apparatus was demonstrated by Miss E. G. Tadros who is working under the direction of Dr. W. D. Wright. In this apparatus, with one eye an observer could view through an optical system a small colour pattern from the Munsell series (about 1 inch square) mounted on a white background and illuminated by a chosen reference light source. The other eye could view a similar field illuminated by the light source under test. In this second field, Munsell colour samples were introduced in turn into the same relative position in the field as the Munsell test pattern seen by the other eye, until one was found which, after the eyes had become adapted, appeared to match the comparison pattern under these binocular viewing conditions. This procedure was repeated for a series of colour patterns on the comparison side. The results so obtained were an indication of the chromatic adaptation under the test illuminant. The accuracy obtained under these rather more practical conditions was not, of course, as high as when using a binocular colorimeter.

Measurements made by Wright and Hunt in binocular colorimeters and by Tadros in the binocular colour viewer, described above, give quantitative indications of the extent to which the eye becomes adapted in its colour response. All these observations show that there is a large

TABLE 3.

PERCENTAGE LUMINANCE IN SPECTRAL BANDS OF 80 WATT MCF/U LAMPS USED IN BINOCULAR VIEWER.

Type of Lamp	Percentage Luminance in Spectral Bands.							
	1 0·38-0·42μ	2 0·42-0·44μ	3 0·44-0·46μ	4 0·46-0·51μ	5 0·51-0·56μ	6 0·56-0·61μ	7 0·61-0·66μ	8 0·66-0·76μ
80 w. Daylight	0·009	0·33	0·35	4·9	38·2	48·2	7·8	0·22
80 w. Natural	0·011	0·37	0·34	4·85	37·4	47·9	8·9	0·29
80 w. Mellow	0·007	0·31	0·11	2·06	28·2	51·3	16·8	0·47
80 w. Warm White	0·005	0·30	0·14	2·35	29·8	55·6	11·5	0·33
80 w. Colour Matching	0·015	0·42	0·62	9·5	44·9	34·3	9·9	0·41

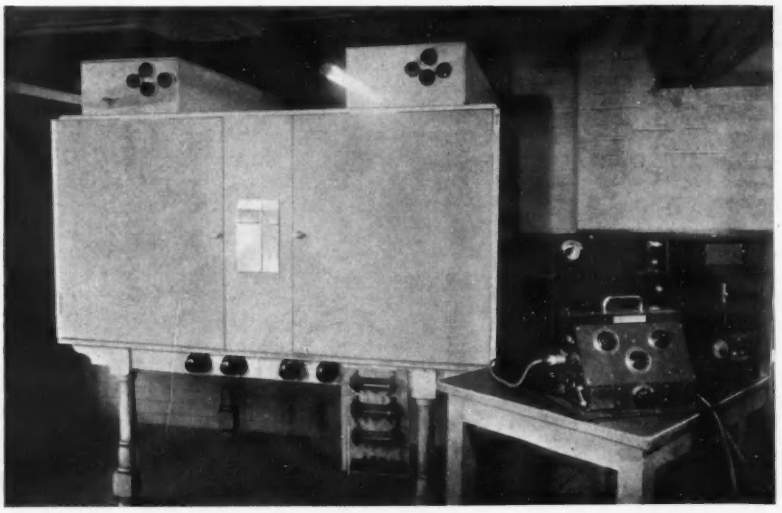

Fig. 3.—Exterior of binocular colour viewing cabinet.

measure of compensation in the colour response of the eye after adaptation, dependent on the colour, luminance and extent and form of the field adjacent to the test sample.

By simultaneous comparison, as in a normal type of monocular visual colorimeter, or as indicated by a physical colorimeter which gives results in accordance with the Standard Observer, a shift in chromaticity may be indicated when a pattern is illuminated in turn by two different forms of illuminant (see fig. 2). Measurements in the binocular colorimeter and viewer show, however, that when the eye is fully adapted to a particular light source the chromaticity of samples appears to change by only a proportion of the objective shift indicated by the Standard Observer.

It will be seen, therefore, that the binocular viewing technique has the great advantage that it enables an assessment to be made of the appearance of coloured surfaces or fields of view when the eye has become chromatically adapted, as, in fact, occurs in most practical conditions. For example, only in a small proportion of lighting installations can one observer see the colour-rendering of one class of light source and installation simultaneously with that of another. Such conditions may occur

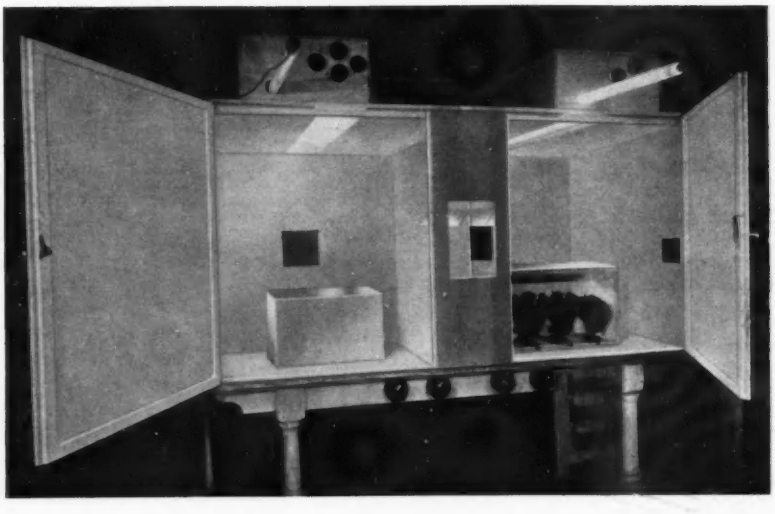

Fig. 4.—Interior of binocular colour viewing cabinet.

where a room is illuminated by daylight and an adjacent room by artificial light, in a situation where it is possible to view the two rooms simultaneously and when the decorations in the two rooms involve the use of the same coloured materials. With the exception of colour matching applications, the interest is not in the exactness of the objective colour-rendering properties of the light source under simultaneous comparison with that of daylight or some other illuminant such as tungsten filament lamps, but in the manner in which colours appear to be rendered by the light source in question to people who are in the room for some considerable time, so that their eyes have become conditioned to the light from the source and the coloured decorations of the room.

In the Wright and Hunt binocular viewing techniques, only small fields of view were used, and in the Tadros technique the limit to the usefulness of the observations may be set by the available Munsell patterns which do not extend to very saturated colours. Preliminary experiments by the authors indicated that the binocular viewing technique might prove a valuable tool for exploring the objective-subjective relationships in the extended fields of application which they wished to investigate. The apparatus would, however, need to be different from the Tadros instrument. A modified binocular viewing apparatus was, therefore, designed and constructed as indicated in the next section.

(5) MODIFIED BINOCULAR COLOUR VIEWING APPARATUS.

Fig. 3 shows a photograph of the binocular viewing apparatus which has been developed by the authors. As will be seen this comprises two adjacent cabinets approximately 3 ft. 6 ins. cube. In the top centre of each cabinet is a diffusing window of flashed opal glass 4 ins. wide, extending from the back to the front of each cabinet.

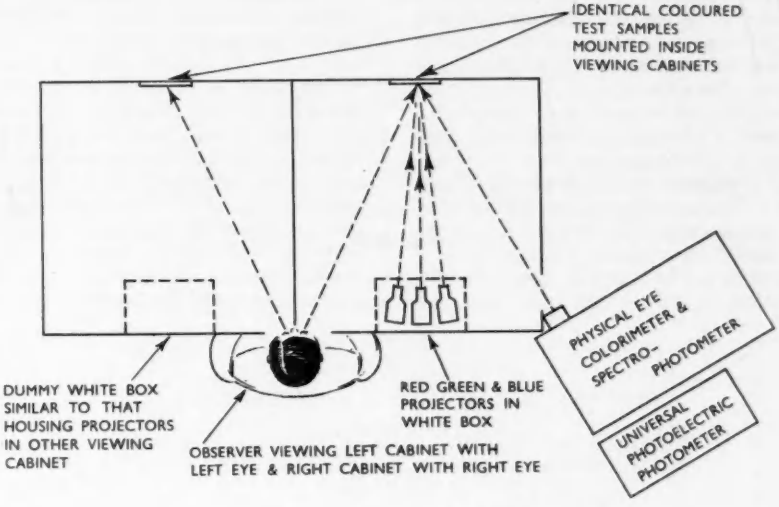
IDENTICAL COLOURED TEST SAMPLES MOUNTED INSIDE VIEWING CABINETS
PHYSICAL EYE COLORIMETER & SPECTRO-PHOTOMETER
UNIVERSAL PHOTOELECTRIC PHOTOMETER
DUMMY WHITE BOX SIMILAR TO THAT HOUSING PROJECTORS IN OTHER VIEWING CABINET
RED GREEN & BLUE PROJECTORS IN WHITE BOX
OBSERVER VIEWING LEFT CABINET WITH LEFT EYE & RIGHT CABINET WITH RIGHT EYE

Fig. 5.—Diagrammatic arrangement of binocular colour viewer.

Above each window is a box with two compartments, one of which is fitted with a series of fifteen 100 watt tungsten filament lamps and the other compartment with a tubular fluorescent lamp. The insides of these compartments are covered with white asbestos sheeting which serves the dual purpose of acting as a heat resisting lining and also as a diffuse reflecting surface. These two boxes each contain two types of light source and can be moved so that one or other of the two compartments registers with the respective diffusing windows in the top of the viewing cabinets.

The insides of the two viewing cabinets, which can be seen in fig. 4, are lined with white cartridge paper to simulate light wall decoration as in a room, and adjacent apertures at the front of each cabinet enable the observer to view with one eye the left-hand cabinet and with the other eye the right-hand cabinet. The dividing partition fits up against the observer's face, and so restricts the vision of the left eye to the left

cabinet and the right eye to the right cabinet, as indicated diagrammatically in fig. 5. By switching arrangements, a suitably selected number of the fifteen tungsten filament lamps in the light box can be operated simultaneously. The level of illumination is adjusted so that it is sensibly the same in both the left and right hand cabinets. The tungsten filament lamps are used in the manner indicated below to simulate standard illuminants *A*, *B* and *C*.

This simple binocular viewing arrangement has the added advantage that, if required, the adjacent apertures on the front of the cabinets can be viewed simultaneously by the observer if he stands away from the cabinet. A ready comparison can, therefore, be made of the appearance of the colours seen simultaneously with that under binocular viewing conditions.

Standard illuminant *A* (S_A) is obtained from the tungsten filament lamps alone, operating at the colour temperature of 2,850 degs. K. Standard illuminant *B* (approximately 4,800 degs. K). is normally obtained by using an internationally specified liquid filter in conjunction with S_A, but for convenience in the present experiments a Chance OB9 temperature conversion filter to give an approximation to Standard Illuminant *B* was mounted in front of the left eye of the observer. The absorption of the filter was compensated by switching on the appropriate number of tungsten filament lamps. Standard illuminant *C* was similarly approximated by an OB9 temperature conversion filter in front of the eye, which increased the colour temperature to approximately 6,500 degs. K, the full number of tungsten filament lamps being used in this case to compensate for the filter absorption.

The coloured samples to be tested were mounted on aluminium plates, 7 ins. by 7 ins., with a white card between the fabrics and the metal plate. These were set up in the two cabinets on the centre of the walls opposite to the observer (fig. 5). This latter position allows the samples to be measured for their chromaticity co-ordinates by means of the Physical Eye Colorimeter and Spectrophotometer[2] which is mounted against the apparatus in the manner

TABLE 4.

ILLUMINANTS COMPARED IN BINOCULAR VIEWER.

Illuminant in Left-hand Side of Viewing Cabinet.	Illuminant in Right-hand Side of Viewing Cabinet.
Column 1.	Column 2.
Standard Illuminant *A* (Tungsten at 2,850 degs. K.)	Standard Illuminant *B* approx. (Tungsten 2,850 degs. K. plus 2·36 mm. thick OB9 temperature conversion filter producing colour temperature 4,800 degs. K.)
Ditto.	Mellow Colour Fluorescent Lamp.
Ditto.	Warm White Colour Fluorescent Lamp.
Standard Illuminant *B* (as in Column 2).	Daylight Colour Fluorescent Lamp.
Ditto.	Natural Colour Fluorescent Lamp.
Standard Illuminant *C* (Tungsten 2,850 degs. K. plus 3·25 mm. thick OB9 filter to yield 6,500 degs. K.)	Colour Matching Fluorescent Lamp.

ndicated in figs. 3, 4 and 5. Three projectors, hown in the right hand cabinet in fig. 4, are rranged so that, if required, red, green and blue ight can be projected on to the specimen under est. Masks in the projectors restrict the light o the area of the coloured pattern. The proportions of coloured light are adjusted by means of he three resistances shown on the right in figs. 3 nd 4.

6) OBSERVATIONS ON BINOCULAR APPARATUS.

The coloured specimens which were measured objectively and are referred to in section (2), have also been observed in the binocular viewing apparatus described in the previous section.

First, the observer viewed all the pairs of colour patterns in turn, with Standard Illuminant *A* in both viewing cabinets, to check that within the required accuracy the coloured patterns appeared the same colour to each eye. Provided that this was confirmed the observer subsequently carried out the series of tests detailed in Table 4.

Using the Physical Eye Colorimeter and Spectrophotometer, an objective measurement was made of the coloured sample in the right-hand side of the binocular viewer, when illuminated by the appropriate light source.

The observer then viewed binocularly one pair of coloured samples illuminated by the sources to be compared, and after five minutes adaptation to the respective fields of view, if the test samples appeared different in colour, the three colour projectors were switched on and their contributions adjusted by means of the resistances until the samples appeared to match. During the adaptation period the observer did

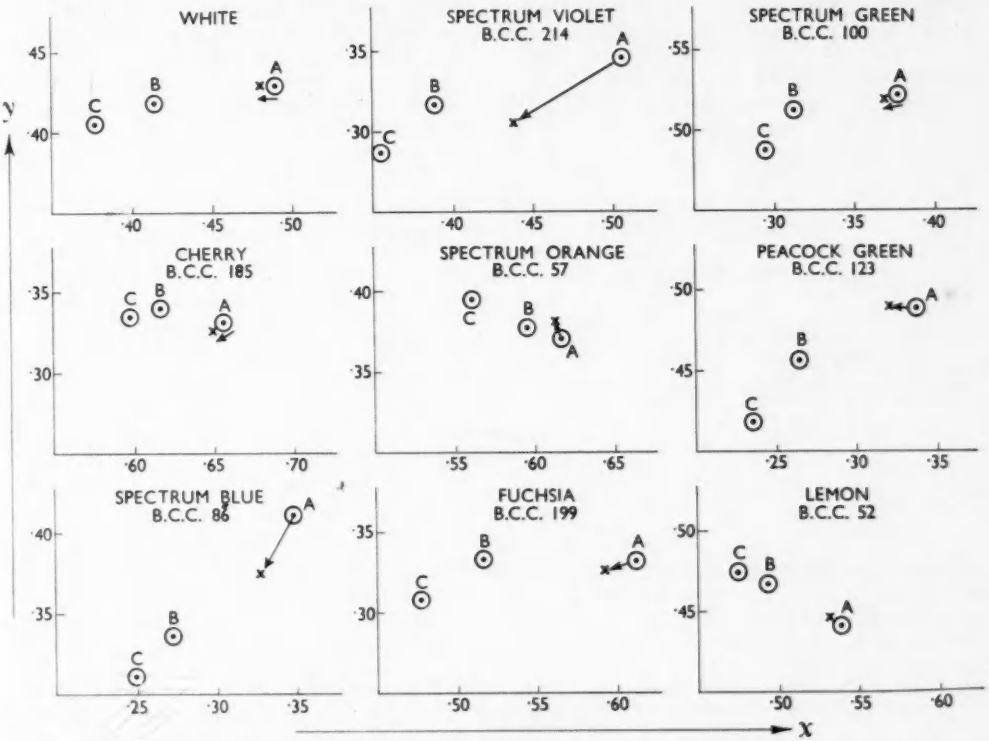

Fig. 6.—C.I.E. Chromaticity co-ordinates of samples in binocular viewer. Illumination approximately 75 L/sq. ft.
A Sample illuminated by standard illuminant *A* = 2,850 degs. K.
B Sample illuminated by standard illuminant *B* = approximately 4,800 degs. K.
C Sample illuminated by standard illuminant *C* = approximately 6,500 degs. K.
X Objective measurement of the samples when illuminated by S_A plus coloured light from projectors to give a subjective binocular match with the sample in the adjacent cabinet illuminated by S_B, the eyes being adapted to S_A and S_B respectively.

not fixate on the coloured sample, but allowed his eyes to look round the cabinet in a random manner, as would occur if he were in a room. Using the Physical Eye, an objective measurement was made of the chromaticity co-ordinates of the pattern on which the coloured light was projected. This procedure was repeated for all pairs of coloured specimens. The results of a preliminary set of measurements by one observer, together with a few cross checks by a second observer are plotted in chromaticity diagrams in figs. 6 and 7.

In addition to the above observations and measurements, just before making each binocular comparison, the observer noted the simultaneous colour appearance of the surround fields and colour patches. This could be done by standing back from the cabinet, as indicated in section (5). In these preliminary observations the simultaneous comparison could not be made where a filter was used in front of one eye to simulate Standard Illuminants *B* and *C*. This will be possible in all cases when OB9 glass of the appropriate thickness becomes available in sizes large enough to cover the whole of the diffusing window below the tungsten filament lamps in the light box.

(7) DISCUSSION OF PRELIMINARY RESULTS

It will be seen from the preliminary data in figs. 6 and 7 that when the eye is fully adapted to the surround field the chromaticity shifts

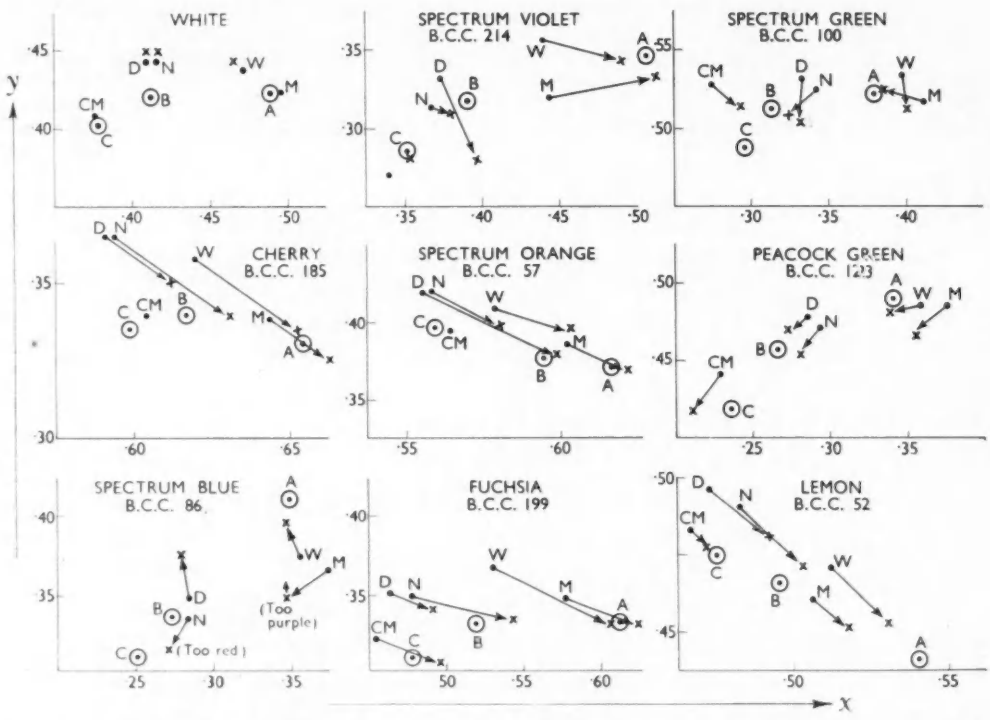

Fig. 7.—C.I.E. Chromaticity co-ordinates of samples in binocular viewer. Illumination approximately 75 L/sq. ft.

A Sample illuminated by standard illuminant *A* = 2,850 degs. K.
B Sample illuminated by standard illuminant *B* = 4,800 degs. K.
C Sample illuminated by standard illuminant *C* = 6,500 degs. K.
D Sample illuminated by 80 watt daylight MCF/U.
N Sample illuminated by 80 watt natural MCF/U.
M Sample illuminated by 80 watt mellow MCF/U.
W Sample illuminated by 80 watt warm white MCF/U.
CM Sample illuminated by 80 watt colour matching MCF/U.
X Objective measurement of subjective match as in fig. 6, but with samples illuminated by fluorescent lamps and compared with S_A, S_B, or S_C in the manner detailed in Table 4.

re considerably less than those indicated by the objective measurements in section (2). This would be expected in view of the work of Wright and Hunt. In the present example the observations were carried out on samples approximately ins. by 7 ins., at a viewing distance of 3 ft. ins., as it is understood that this approximates to the conditions mostly used in practice by dyers and other colour workers when judging the colour of dyed samples or papers.

It is interesting to note from the results that in all the examples where simultaneous comparisons are made in this binocular instrument there was a marked difference in the colour appearance, not only of the coloured patterns, but also of the off white cartridge paper surround forming the inside of the viewing cabinet. Under the binocular viewing condition, however, after five minutes' adaptation of the eyes to the respective illuminants being compared, in several cases the white surround fields appeared to be of the same colour and the difference in the apparent colour of the specimens was considerably reduced. This effect was most marked when comparing Mellow fluorescent lamps with tungsten at 2,850 degs. K., i.e. Standard Illuminant *A*. In fact, the white surround fields appeared almost the same colour immediately they were viewed binocularly.

Attention is drawn to the objective chromaticity co-ordinates of the cartridge paper used to line the viewing cabinets. It will be noted from Table 5 that the chromaticity co-ordinates of a sample of the cartridge paper when illuminated directly by Standard Illuminant *A* are only slightly different from those of magnesium oxide under the same illuminant. Objective chromaticity measurements were also made of the cartridge paper when forming the wall of the right-hand viewing cabinet and illuminated by the tungsten lamps, i.e. Standard Illuminant *A*, as used throughout the colour viewing tests. The measurements were made on the area of the cartridge paper normally behind the coloured test specimen. In this position the paper is illuminated by a mixture of direct light from the tungsten lamps after passing through the flashed opal glass diffusing window and light which has suffered multiple reflections from the walls of the viewing cabinet. From the results in Table 5 it will be seen that the chromaticity co-ordinates so measured are appreciably different from those of the cartridge paper sample directly illuminated by Standard Illuminant *A*.

This chromaticity displacement does not affect the general preliminary conclusions drawn from these experiments, but it is of interest as an indication of the marked effect of inter-reflections on chromaticity of near neutral decorations. Clearly, coloured decorations would have an even greater effect in modifying the colour appearance of objects under any given illuminant.

It is stressed that the few preliminary results so far obtained with the apparatus may not subsequently be found representative. These results were, however, thought to be of sufficient interest to indicate the potentialities of the method. It is hoped to make further extended series of measurements with the apparatus and to link the results with the eight band spectral luminance values. These results will probably be reported in a later issue of this Journal.

TABLE 5.

CHROMATICITY CO-ORDINATES OF WHITE CARTRIDGE PAPER.

Chromaticity Co-ordinates of MgO Illuminated by Standard Illuminant A. (Light Incident at 45° to Normal.)		Chromaticity Co-ordinates of Cartridge Paper.			
		Directly Illuminated by Tungsten at 2,850 degs. K. i.e., S_A, Incident at 45° to Normal.		In Binocular Viewer Illuminated diffusely by Tungsten at 2,850 degs. K. i.e., S_A.	
x	y	x	y	x	y
·4475	·4075	·4525	·410	·498	·430

(8) BINOCULAR VIEWER AS A TEST FOR DECORATION MATERIALS.

This binocular apparatus could be used to enable various pigments and coloured materials to be judged for their suitability in decoration schemes. For example, where a choice of

distempers, paints or other forms of decoration for a room is being considered, particularly when it is desired to be sure whether or not such decorations will be suitable not only in daylight but also under fluorescent or other artificial light, a test can quickly be made. Detachable panels which can form false walls to the viewing cabinets could be painted with the pigment to be tested. This could first be viewed simultaneously and then by the binocular viewing method with the two light sources under which the decorations will in practice be seen. The simultaneous view will indicate the immediate effect to be expected, whereas the binocular view after adaptation for five minutes or more will indicate the extent of the chromatic adaptation for this particular viewing condition.

Comparisons of this type might usefully be extended to test the effect of various colour schemes. For this purpose the cabinets could be appropriately decorated to form miniatures of the proposed scheme and judgments made of their suitability, thus avoiding the necessity for full scale trials.

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Cold Cathode Lighting at Victoria Station

The cold cathode lighting in the reconstructed Eastern Section Booking Hall at Victoria Station is both decorative and efficient.

Local illumination for time-tables and notices is unnecessary. A single line of intermediate white tubing gives additional lighting at the ticket windows.

Characteristics of Fractional Horsepower Single Phase Induction Motors

By the late *E. K. BOTTLE, B.Sc., A.C.G.I., A.M.I.E.E.
Fractional Horsepower Motor Design Department, Witton.

The problem of creating a starting torque in the single phase induction motor is briefly outlined, the various methods of solving it giving rise to particular types of motors. A review of the general characteristics of f.h.p. motors follows, and comparisons are made with large polyphase motors. Finally, the various types of motor are considered in detail and attention is drawn to their individual peculiarities.

INTRODUCTION.

SINGLE phase induction motors having outputs of under 1 h.p. can be divided into two groups: those down to and including $\frac{1}{8}$ h.p. and those under $\frac{1}{8}$ h.p. The latter are often distinguished by the name "sub-fractional h.p.," but for the purposes of this paper they are included in the general classification.

As is well known, an induction motor excited directly from a single phase supply will develop a torque only when the rotor is turning. It is therefore necessary to make special arrangements to provide a starting torque for this type of machine. The most usual method is to fit a second stator winding, displaced round the periphery from the main winding. This auxiliary or starting winding is fed with current which differs in phase from the current in the main winding, although both are derived from the same impressed voltage. The combination of displaced windings and out-of-phase currents sets up a rotating field, albeit a rather imperfect one, which reacts upon the squirrel cage rotor to produce a starting torque in a manner similar to that of a polyphase motor. The phase difference between the currents is obtained by designing the windings to have different impedance characteristics, and the several methods of doing this give rise to the various types of motor, i.e. split phase, capacitor start, capacitor run, and shaded pole.

It may be noted here that, unlike integral h.p. single phase motors, fractional h.p. machines are normally self contained in their starting arrangements, and so can be switched straight on to the supply without the need for auxiliary equipment. Where it is necessary to open-circuit a winding after starting this is done automatically, usually by means of an internal centrifugal switch.

Standing apart from the other kinds of single phase induction motors mentioned above is the repulsion-start induction-run type. In place of a squirrel cage, its rotor is wound like a D.C. armature, while there is only one winding on the stator. The motor starts and runs up as a commutating machine. When it reaches a certain speed the commutator is automatically short-circuited and the machine then functions as an induction motor.

GENERAL CHARACTERISTICS.

Performance Curves.

Performance curves of f.h.p. single phase induction motors exhibit a family likeness to those of large polyphase machines, but have different relative proportions. In the case of sub-fractional h.p. machines the deviation is more marked, but these, too, can be said to follow the general laws of the classic text-book induction motors. As a matter of interest, figs. 1 and 2 are given to compare the performance of a $\frac{1}{2}$ h.p. split phase motor with that of a 50 h.p. three phase machine. The curves are put on to a common base by expressing outputs in terms of the normal full load value in each case. The smaller machine—as is to be expected—works at a higher slip and has lower efficiency and power factor but shows to advantage in respect of relative starting torque.

*Author of "Fractional h.p. Electric Motors—A Guide to types and applications." Charles Griffin & Co. Ltd., London.

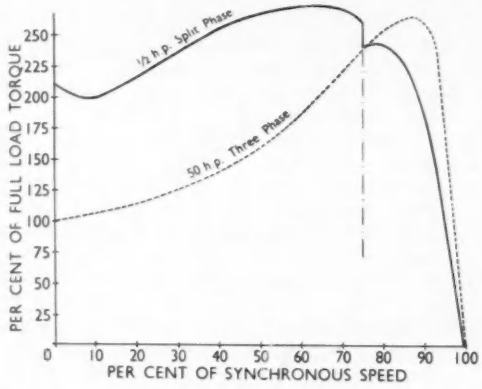

Fig. 1.—Comparison of speed-torque curves for ½ h p and 50 h.p. induction motors.

SPEED.

The range of speeds available in f.h.p. induction motors is extremely limited compared with that obtainable on large polyphase machines. In practice, over 90 per cent of them are wound for 4 poles, most of the remainder being wound for 2 poles. It is not feasible to wind for 8 or more poles, except in the case of the completely specialised ceiling or exhaust fan motors.

One result of this limitation is that there is no possibility of compensating for differences in supply frequencies by varying the choice of the number of motor poles. Appliances intended for export to countries where the supply frequency is 40 or 60 cycles will therefore, in general, have to be modified to suit the changed motor speed if they were originally designed for a 50 cycle market.

Broadly speaking, motor speed control is possible only in special circumstances and then only with the sub-fractional group of motors. There is no equivalent of the variable rotor resistance controller used on large slipring motors, whereby it is possible to develop the same value of maximum torque at different speeds. In cases where the speed control of sub-fractional h.p. motors is attempted it is obtained by depressing the entire torque speed curve so that the particular torque required is closer to the pull-out value and is therefore developed at a higher slip. To take advantage of this form of control the speed torque characteristics of the driven appliance and of the motor must be so proportioned that they interact to give a stable running condition.

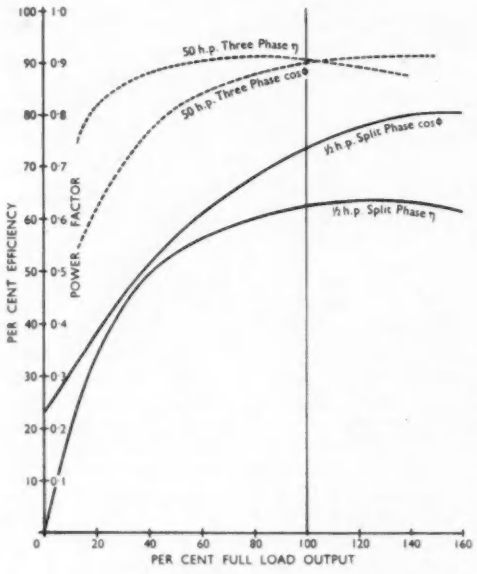
50 h.p. Three Phase η
50 h.p. Three Phase cosφ
½ h.p. Split Phase cosφ
½ h.p. Split Phase η
PER CENT EFFICIENCY
POWER FACTOR
PER CENT FULL LOAD OUTPUT

Fig. 2.—Comparison of efficiency and power factor curves for ½ h.p. and 50 h.p. induction motors.

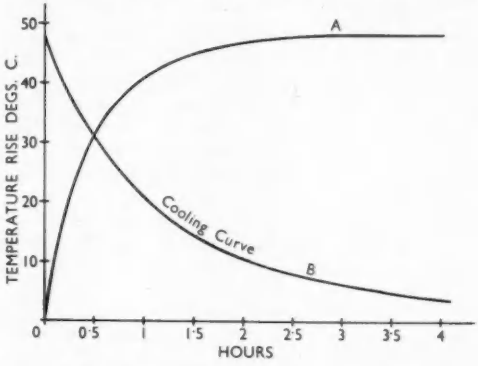

Fig. 3.—Time-temperature curves for a ventilated ½ h.p. 1,440 r.p.m. split-phase motor.

TEMPERATURE RISE.

Whereas large motors may take up to six hours to reach their final temperature on a load run, the period for f.h.p. motors is considerably shorter. Ventilated machines of around ½ h.p. sizes attain substantially steady temperatures in two hours. For sub-fractional h.p. sizes finality is reached in about one and a half hours. In general, therefore, any application for which the load period exceeds a half hour will require a continuously rated motor. Moreover, since the no load losses of small single phase induction motors are comparable with the full load losses, little benefit results from duty cycles in which

he motor runs continuously on light load and is ubject only to intermittent periods of full load.

Fractional h.p. motors are covered by British Standard No. 170/1939 and this permits a temperature rise of 50 degs. C. on the windings. The temperature gradients within the machine are generally low, so that the temperature of the stator iron often approximates to that of the windings. In one common type of construction the back of the stator stampings forms the outside surface of the machine so that parts which are exposed may become uncomfortably hot to the touch while the temperature of the windings is still within the permitted limit.

Fig. 3 presents typical time-temperature curves for a ½ h.p. split phase motor. Curve *A* shows the rise of the stator winding temperature when the machine is run on full load. Curve *B* is a cooling curve for the winding, showing how high its temperature still remains above the ambient at various intervals after shut down.

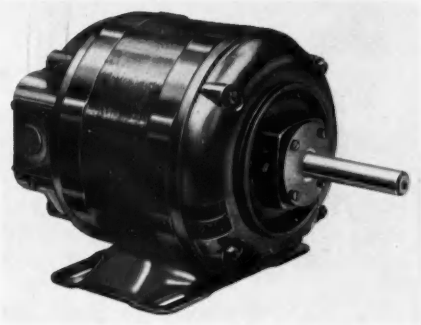

Fig. 4.—½ h.p. 2,800 r.p.m. split-phase motor.

SPLIT PHASE MOTORS.

The split phase motor (fig. 4) is the most useful general purpose machine for powers between ½ and ⅛ h.p. Its starting torque of about twice the full load value is adequate for almost all applications except compressors, and it is cheaper to make than are the capacitor start and repulsion start types.

It suffers from two limitations, both connected with its starting characteristics. First, it takes a heavy starting current so that, unless standstill torque is to be sacrificed, the current rush taken by motors of over ½ h.p. may be objectionable. In any case, the line drop caused by this current is likely to prejudice starting performance in the larger size motors unless the supply wiring is very ample.

The second limitation is due to the fact that the starting winding is short-time rated. This means that the split phase motor, while quite suitable for infrequent starts, is not generally recommended for duties where the number of starts per hour exceeds three or four. The motor is also unsuitable in cases where, due to load inertia or other causes, the starting period is prolonged for more than two seconds.

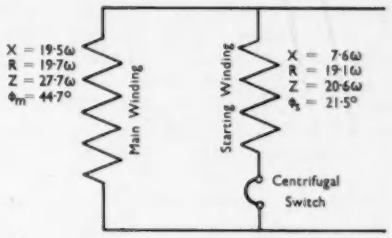

Fig. 5.—Schematic diagram of ½ h.p. 1,440 r.p.m. 225 volt split-phase motor at standstill.

Fig. 5 shows a schematic arrangement of connections for a ½ h.p. split phase motor. Because of the different proportions between reactance and resistance in the starting and running windings the current in the former leads that in the latter by some 23 degrees (see fig. 6). A rotating field is thus set up by the stator and reacts with the squirrel cage winding of the rotor to produce a starting torque which may be calculated from the formula :

$$T=\frac{1\cdot88+2p}{16f}k.I_s.I_m.R'_2.\ \sin\alpha\ \text{lbs. ft.}$$

Where :

p =number of pairs of poles. f=frequency.
k =ratio of starting winding turns to running winding turns.
R'_2=Rotor resistance referred to stator running winding.
α =angle between I_s and I_m.
I_s =current in starting winding.
I_m =current in running winding.

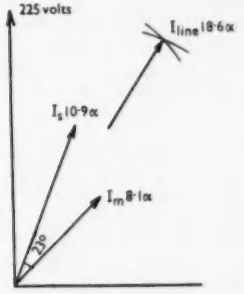

Fig. 6.—Vector diagram for ½ h.p. 225 volt split-phase motor at standstill.

The power-factor of the current in the starting winding is made high by winding it with fewer turns and a smaller gauge of wire than are used for the running winding. This arrangement does away with the need for an external resistance such as is used in the starters of integral h.p.

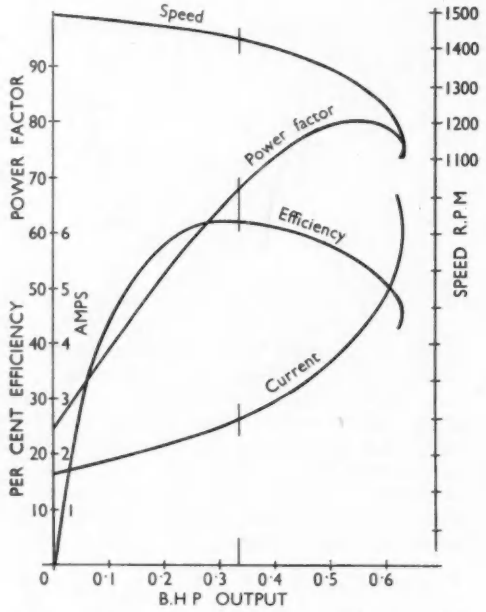

Fig. 7.—Performance curves for ½ h.p. 1,420 r.p.m., 225 volt, 50 cycle split-phase motor.

split phase motors. It does, however, lead to very high current densities in the starting winding and so is responsible for the short-time rating of this winding.

When the rotor reaches about 75 per cent of synchronous speed the centrifugal switch, which is in series with the starting winding, opens and the motor functions with the running winding alone.

The direction in which the starting torque is exerted depends upon the relative direction of the current flow in the two windings. This can be reversed by interchanging the two leads of one of them. Although the machine can therefore be classed as "reversible" this characteristic can only be obtained so long as the two windings are energised at the same time. Since the starting winding is open-circuited by the centrifugal switch when the motor is at full

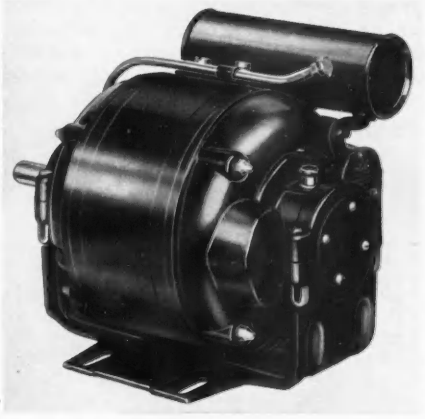

Fig. 8.—¼ h.p. 1,450 r.p.m. capacitor start motor.

speed it is not possible to reverse this type of machine by "plugging", as can be done with a three phase motor. It must therefore always come to rest, or at least to a very low speed, before an attempt is made to change the direction of rotation.

TABLE 1.

TYPICAL PERFORMANCE OF 50 CYCLE, SPLIT PHASE, 4-POLE MOTORS.

Horse-power	Speed R.P.M.	Efficiency per cent	Power Factor	Torque (lbs. ft.)		Amps. at 225 volts	
				Pull out	Starting	Full Load	Starting
⅛	1,430	57	·61	1·1	0·9	1·2	10
⅙	1,440	58	·62	1·4	1·2	1·5	12
¼	1,445	61	·65	2·2	1·8	2·1	18
⅓	1,450	62	·68	2·9	2·4	2·6	22
½	1,450	63	·74	4·3	3·6	3·3	34

Fig. 7 shows performance curves for a typical split phase motor rated at ⅛ h.p. 1,440 r.p.m. on 225 volt, 50 cycle supply. Table 1 outlines the performance to be expected over a range of 4-pole, 50 cycle ventilated motors designed for outputs between ⅛ and ½ h.p.

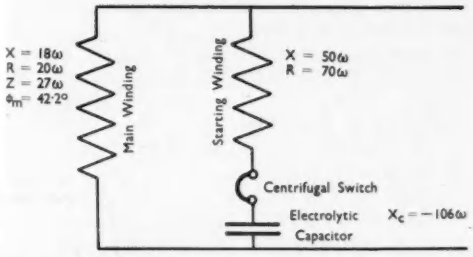

Fig. 9.—Schematic diagram for ¼ h.p. 1,440 r.p.m. 225 volt capacitor start motor at standstill.

CAPACITOR START MOTORS.

The capacitor start motor (fig. 8) is used for outputs from 1 h.p. down to ⅛ h.p. Its starting performance is superior to that of the split phase type, giving a higher torque for a lower starting current. It is extensively used for driving refrigerator compressors and for similar duties where a torque in excess of that given by a split phase motor is required. For outputs of ½ h.p. and upwards it is the most useful type of general purpose motor, since its starting current is reasonable and the machine is less costly than a repulsion start motor of equal power.

The phase displacement in the starting winding is provided by an electrolytic capacitor which is put in series with it. This type of capacitor is short-time rated, but not to the same extent as is the starting winding of a split phase motor. The machine is therefore capable of handling fairly severe starting duties. Where the duration of the starting period does not exceed one second, the number of starts per hour can be as high as twenty. On the other hand, occasional starting periods of as long as ten seconds can be handled at intervals of an hour or more.

The capacitor is normally mounted on the body of the motor so that the machine is a self-contained unit. Fig. 9, shows schematically the standard method of connections for supply systems in the 200/250 volt range. Capacitor start machines have similar stator and rotor cores to those used for split phase motors and the same type of winding, but the proportions between the starting and running coils are different. The starting winding is open-circuited by a centrifugal switch when the rotor reaches about 75 per cent of synchronous speed.

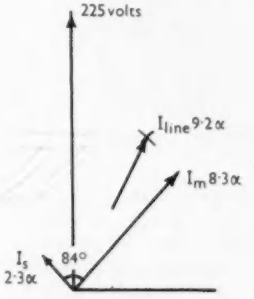

Fig. 10.—Vector diagram for ¼ h.p. 225 volt capacitor start motor at standstill.

The vector diagram for standstill conditions is given in fig. 10. Comparing this with fig. 6, which was for a split phase motor, it will be seen that the current in the starting winding now leads that in the running winding by substantially 90 degs. and is consequently much more effective in producing torque. At the same time the total current is considerably lower. It must be noted that as the motor accelerates the voltage across the capacitor rises to a value well above that of the supply. For this reason a 220 volt motor will require a capacitor rated at 350 volts. In the event of replacing the capacitor it is essential to see that the new one has the same voltage rating as the original.

An alternative method of connecting the windings is shown in fig. 11. This is the "Tee" connection. It is used for voltage supplies in

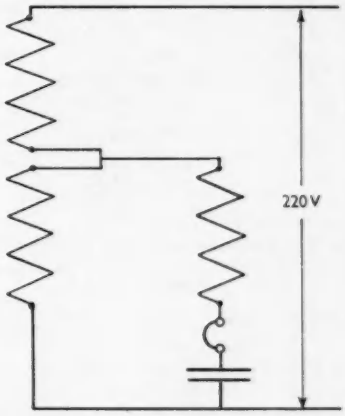

Fig. 11.—"Tee" connection for capacitor start motor.

the 220/250 volt range, but except for dual voltage working it offers no advantage over the standard connection and it requires an additional lead from the running winding. A Tee-connected machine needs four times the capacity of the standard connection but, on the other hand, the capacitor need only be rated for half the voltage.

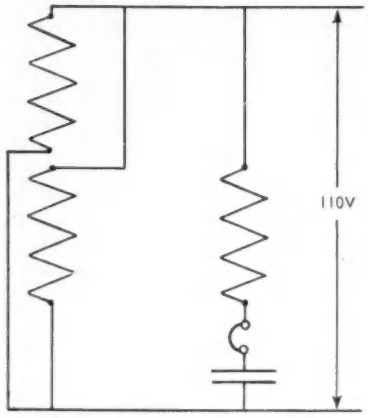

Fig. 12.—Capacitor start motor with paralleled running winding for use on 110 volts which can be reconnected "Tee" for use on 220 volts.

By using a Tee connection it is possible to make a motor which will be suitable for both 110 volt and 220 volt circuits, or any other 2 to 1 combination, by reconnection in the terminal box. This is done by putting the two halves of the running winding in parallel for the lower voltage, and connecting the starting winding plus capacitor in parallel with the modified running winding (see fig. 12).

The standstill torque developed by a capacitor start motor is a function of the value of capacity used. Beginning at zero for no capacity it reaches a maximum when the reactance of the capacitor is equal to the standstill impedance of the starting winding. For values below about 60 per cent of the maximum torque conditions the starting torque is roughly proportional to the amount of capacity used. Since commercial capacitors are normally rated to have only a positive tolerance on capacity, it is usual to select a nominal size below that required to give the maximum torque.

Capacitor start motors are mostly designed to comply with Amendment No. 2 of British Standard No. 170/1939 which lays down the performance required for driving refrigerator compressors, and which quotes 300 per cent of full load for the minimum acceptable starting torque. This value is obtained for approximately four to five times the full load current.

The performance on load of a capacitor start motor is substantially the same as that of a split phase machine of equal power, so that the figures quoted in Table 1 apply to both types. A further point of similarity with the split phase motor is in the method of reversing the rotation, namely by interchanging the two leads coming from the starting winding. Since this winding is in series with a centrifugal switch the limitation which requires the motor to come to rest before reversing applies in this case also.

CAPACITOR RUN MOTORS.

For reasons that will become apparent later, the capacitor run motor (fig. 13) is usually restricted to outputs below 1/15 h.p.

Like the types of machine already described, it has two sets of windings on the stator. A capacitor is connected in series with the one, called the "auxiliary" winding, and the combination is usually put across the supply in parallel with the second, or "main", winding, as shown in fig. 14(a). Occasionally the connection shown in fig. 14(b) is used, this being more suitable for very small outputs since it requires a lower number of conductors in the winding.

Fig. 13.—1/300 h.p. 1,250 r.p.m., 115 volt capacitor run motor and capacitor, compared in size with a halfpenny.

The machine differs from the capacitor start motor in having no centrifugal switch, so that the capacitor is in circuit during the running as well as the starting period. This necessitates the use of a continuously rated paper dielectric type

of capacitor, which is usually not mounted on the body of the motor. The voltage rating of the capacitor when connected as fig. 14(a), should be at least 350 volts for use with a 225 volt motor.

At standstill the vector diagram for the motor is generally similar to that shown in fig. 10. As the machine runs up to speed the positions and lengths of the two current vectors change both their absolute and also their relative values, but the current in the auxiliary winding always leads that on the main winding. The complete stator therefore sets up a rotating field when the motor is running as well as at standstill. It is, however, an imperfect one compared with that set up in a true two-phase machine. For a given stator winding and size of capacitor there is only a single value of mechanical loading for which the conditions of a uniform rotating field are met, i.e. with the currents displaced by 90 degs. and the ampere conductors in the two phases equal to one another. In some machines, however, this condition is unattainable within the practical range of loads.

The current in the auxiliary winding increases as the machine accelerates, reaching a maximum value at no load. This sometimes has the unexpected effect of causing the motor to run hotter on no load than on full load.

The auxiliary winding current also increases, at a more than linear rate, with the value of capacity in the circuit. Because of this, the maximum size of capacitor that can be used with a particular motor is limited by the motor heating. The amount of capacity that can be tolerated before overheating occurs rises with

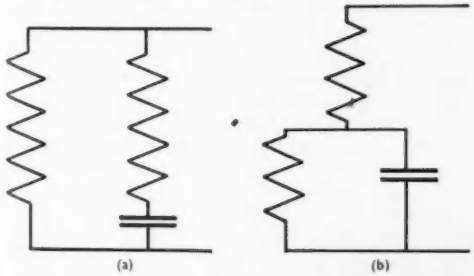

Fig. 14.—Two methods of connecting capacitor run motors : (a) is the more usual.

the size of machine, but at a slower rate than the increase required to produce a fixed proportion of the full load torque at standstill. Since the value of capacity is determined by the running conditions it follows that the starting torque, expressed in terms of full load must decrease as the size of machines increases. Roughly speaking, a starting torque equal to the full load value can be obtained in a 4-pole, 1/15 h.p. machine, while a capacitor run motor designed for ½ h.p. would have a starting torque of only some 20 per cent full load.

Because the auxiliary winding is permanently in circuit, capacitor run motors are capable of being reversed by "plugging", i.e. by inter-

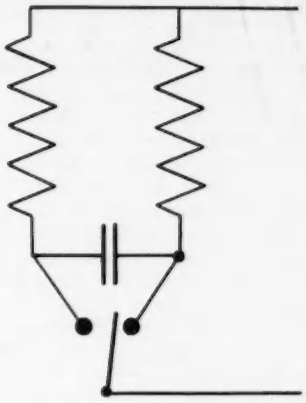

Fig. 15.—Method of reversing the rotation of a capacitor run motor having identical windings.

changing the leads of the auxiliary winding while the machine is running. Unless specifically designed for this duty, however, the braking torque available may be insufficient to cope with a load having high inertia, so that in some circumstances the machine may continue running in a direction opposite to that in which its field is rotating. Capacitor run motors are often made with identical main and auxiliary windings. This arrangement permits of reversing by means of a single pole double throw switch, as shown in fig. 15.

Fig. 16 shows typical performance curves for a 4-pole, 50 cycle capacitor run motor. This machine is rated at 1/20 h.p. when used with a 4 mfd. capacitor, and 1/30 h.p. when used with a 2 mfd. capacitor. Full load efficiencies are of the order of 35 per cent and starting torques on the two ratings are 150 per cent and 120 per cent of full load respectively.

At the other end of the output scale, a 4-pole motor rated at 1/300 h.p. has a full load efficiency of 17 per cent and a starting torque of 200 per cent full load. Machines of this size are preferably run on circuits of 120 volts or less, being fed by a transformer from the normal 200-250 volt supplies. Attempts to wind them to run directly off the high voltage would involve the use of impracticably fine wire

unless the physical size of the motor is increased beyond that needed to give the output. As a compromise the connection shown in fig. 14(b) is sometimes used since this reduces the voltage across each winding.

Capacitor run motors can be designed to give a limited range of speed control. For some

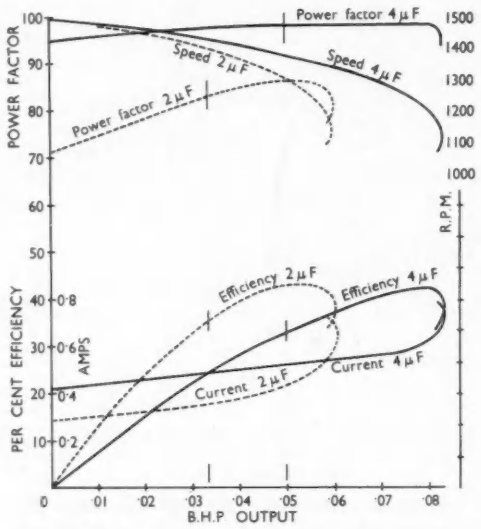

Fig. 16.—Performance curves for capacitor run motor rated at 1/30 h.p., 1,400 r.p.m., with 4 μF capacitor, or 1/30 h.p. with 2 μF capacitor.

applications it is necessary to use a high resistance rotor, to the detriment of the full load performance. For example, a variable speed constant torque motor designed for 1/300 h.p. would have about twice the core length of the machine quoted in the paragraph above, but it would only have some 9 per cent efficiency and would need special arrangements for cooling.

Three methods of reducing the speed are available but, as mentioned earlier, they all work on the principle of lowering the overload capacity so that a greater slip is obtained when developing a particular torque. The methods are :

(*a*) Reduction of voltage at the motor terminals. The speed of ceiling fans is regulated in this way, the voltage reduction being made by putting a tapped resistance in series with the whole machine.

(*b*) Changing the value of capacity. This method is only suitable for very coarse regulation, for example two definite speeds.

(*c*) Shunting the auxiliary winding with a variable resistance.

Capacitor run ceiling fans can be designed to have a speed range of 3 to 1. A coarsely tapped regulator is suitable because the form of the fan blade speed torque curve tends to give stable running even when operating past the point of maximum motor torque. For this reason the use of a low resistance rotor is permissible when driving a fan, and the full load efficiency can be kept correspondingly high.

The case of a constant torque load, e.g. friction, is different, however. Stability at reduced speeds can only be obtained by using a high resistance rotor so that there is no clear cut stalling point on the speed torque curve. At the same time a fine adjustment of the regulator is necessary, such as is given by a slider type resistance. Even with this arrangement a speed reduction of 30 per cent to 40 per cent is all that may reasonably be expected.

SHADED POLE MOTORS.

Shaded pole motors (fig. 17) are usually restricted to outputs below 1/30 h.p. In comparison with capacitor run machines their efficiency is low, while their power factor is of the order of 0·55 to 0·65. Their speed tends to be low, with full load values ranging from 80 per cent to 85 per cent of synchronous speed. Starting torque rarely exceeds 120 per cent of full load and may fall well below the full load value in motors designed specifically for fan drives.

This somewhat indifferent performance is offset by the simplicity, robustness, and cheapness of the motor, which requires no auxiliary equipment such as capacitors, and which has no centrifugal switch. The shape of the speed-torque curve can be modified by changes in the

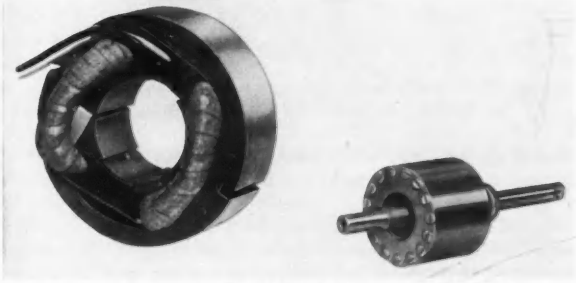

Fig. 17.—Stator and rotor of 1/250 h.p., 2,000 r.p.m., shaded pole motor.

design to a greater extent than is the case with other types of motor. Satisfactory operation depends upon an accurate estimate of the load requirements of the driven apparatus so that a suitable motor characteristic may be chosen. The machine is extensively used for driving both desk and ceiling fans, although on account of its relatively high current and watt consumption it

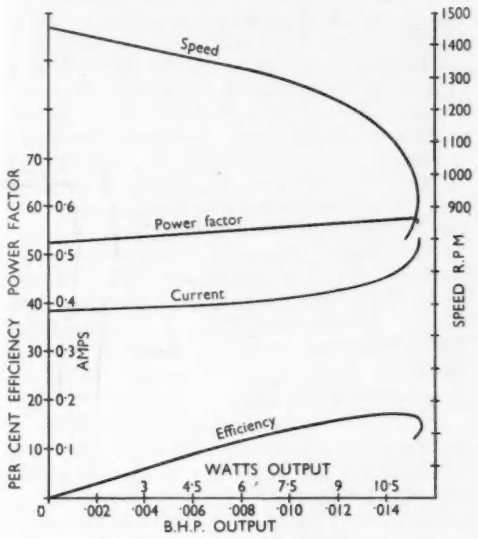

Fig. 18.—Performance curves for 1/100 h.p., 1,280 r.p.m. 225 volt, 50 cycle shaded pole motor.

is increasingly being replaced by the capacitor run motor for the latter type of fan.

The shaded pole motor differs from the machines already described in having no electrical connection between the auxiliary winding and the supply mains. The main winding, instead of being distributed in a number of semi-enclosed slots, is concentrated into field coils which encircle salient poles. The auxiliary winding consists of a number of short-circuited copper loops, one on each pole. One side of a loop lies against the outside of a pole while the other side lies in a narrow slot in the pole face. The area of the pole thus "shaded" by the loop is between a quarter and a third of the total.

Part of the flux set up by the main winding passes down the shaded part of the pole and induces a current in the short-circuited loop. The loop current in turn reacts upon the flux and makes it lag behind that in the other part of the pole. The conditions required to produce a rotating field are therefore present and cause the squirrel cage rotor to develop a starting torque. The performance of the motor is improved by introducing a saturated magnetic shunt between the shaded part of one pole and the unshaded part of the adjacent one. This shunt usually takes the form of a separate iron bridge piece, although in some designs the poles and the bridges are stamped out in a single unit which is then pushed into a yoke after winding.

It is difficult to quote representative performance figures since this type of motor is often designed to drive some particular class of load and the steps taken to meet the special requirements modify the shapes of the curves obtained. Fig. 18, however, is representative of a general purpose 1/100 h.p. 4-pole motor which has a starting torque of 110 per cent and a pull-out torque of 180 per cent of the full load value. As a rough guide to the performance of other sizes of machine the full load efficiency may be taken as ranging from about 10 per cent for an output of 1/300 h.p. to 20 per cent for an output of 1/50 h.p. The full load power factor can be taken as approximately 0·6 throughout this range of output.

Shaded pole motors are capable of a limited amount of speed control by reducing the voltage applied to the motor terminals. A common method of doing this is to put in series with the machine a tapped choke designed to have a power factor approximately equal to that of the motor. For regulating very small machines a potentiometer control is sometimes used. As in the case of capacitor run motors, the rotor resistance may have to be increased to give a useful speed variation when driving a frictional load and this will reduce the efficiency from the figures quoted above. Fan loads, by virtue of the shape of their speed torque curves, can be driven by machines having low resistance rotors.

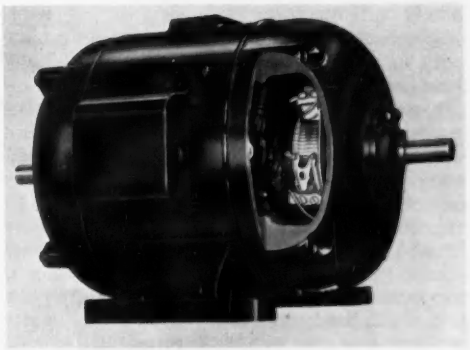

Fig. 19.—$\frac{1}{8}$ h.p. 1,440 r.p.m. repulsion start motor with cover removed to expose brushgear.

The rotation of the field of a shaded pole motor is in the direction of going from the unshaded towards the shaded part of the pole. Since the relationship of these parts is settled at the time of manufacture it is impossible to reverse the rotation of this type of machine once it has been made.

REPULSION START INDUCTION MOTORS.

The repulsion start motor (fig. 19) was developed to deal with difficult starting conditions at a time when the starting performance of split phase motor was very poor. It has now been generally superseded by the capacitor start motor, but there are still special applications where its increased cost is justified. The lower limit of output for which this type of machine is built is about $\frac{1}{4}$ h.p. at 1,400 r.p.m.

The characteristic feature of the repulsion start motor is that it has a higher ratio of starting torque to starting current than any of the types previously considered. Typical values are 2·5 times full load torque for 2·5 times full load current. The reduction in starting current compared with that taken by a capacitor start motor is not great enough to be important for general applications, but it may tip the balance in special cases where the voltage drop in the line is particularly heavy.

The motor also shows to advantage in dealing with special starting problems. It is capable of handling frequent starts, up to, say, two per minute, and can also deal with prolonged starting periods more effectively than can a capacitor start machine. Moreover, if a variable resistance is introduced into the rotor circuit by way of a brush gear a very smooth start, free from all snatch, can be achieved. Repulsion start motors are also recommended for duties where maximum reliability is a first consideration, especially if this requirement is combined with infrequent use, since the latter condition may lead to deterioration of an electrolytic capacitor.

Unlike other single phase induction motors, the repulsion start has only one winding on its stator. It also has a wire wound rotor and commutator generally similar to a D.C. armature. The brushes are shorted together, except in the rare case of the resistance control mentioned above, and are isolated from the main supply. Current is induced in the rotor by transformer action from the stator and the amount and direction of the torque developed at starting is determined by the relation of the brush position to the stator field axis. A graph of torque against brush displacement shows sharp peaks of torque occurring at positions about 20 degs. (electrical) either side of the neutral. It is usual to mark the two brush positions which give the maximum torque, one for each direction of rotation.

When the machine has run up to about 75 per cent of the synchronous speed corresponding to the number of poles and the supply frequency, a centrifugal mechanism short-circuits the commutator. The motor then functions as an induction machine with a full load performance slightly inferior to that of a split phase motor having the same output (see Table 2). In some designs the brushes are lifted off the surface of the commutator at the time of short-circuiting, but the present tendency is to leave them riding permanently.

Reversal of the repulsion start motor while running is impossible, and on a normal machine it is necessary to move the brush position mechanically in order to change the direction of rotation at starting. Electrical reversal, after coming to rest, can be obtained by a special design of stator which has, in effect, an unequal star connected three-phase winding. One pair of phases is excited for one direction of rotation and the other pair for the other direction. This causes the effective axis of the stator field to change relatively to the fixed brush position and so is equivalent to having a variable brush position with a single stator winding. Such an arrangement is uneconomical in copper and requires a larger frame size to develop a given output.

TABLE 2.

FULL LOAD PERFORMANCE OF 4-POLE, 50 CYCLE REPULSION START MOTORS

Horsepower	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{3}{4}$	1
Full load efficiency per cent	56	60	62	67	68
Full load power factor	·60	·63	·65	·68	·68

Design Features of a Modern Induction Pattern Overcurrent Relay

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During recent years Chamberlain & Hookham Ltd. have developed a range of new protective relays. In this article the author indicates some of the problems involved, and the technical advance made in the performance of overcurrent relays produced by the Company.

INTRODUCTION.

WHEN the design of a new overcurrent relay was undertaken, emphasis was laid on the necessity to reduce the volt-ampere burden of the relay, while maintaining the robustness and reliability of existing designs. This emphasis was due to the expanding field of high voltage gear, which increases the difficulties of protective transformer design. Bushing transformers utilise a bar primary which, together with inherently lower current values reduces the ampere turns available, and hence restricts the output obtainable. Further, restricted space limits the extent to which the core section of such transformers may be increased. A review of the conventional construction of these relays showed that their efficiency could be improved considerably, as indicated by the following considerations.

The conventional pattern of relay consists of an upper electromagnet on which is mounted a tapped primary winding, the tappings being led out to a plug bridge. In addition, the top electromagnet carries a secondary winding which energises, either directly or indirectly, the winding on the lower electromagnet, sufficient phase displacement of the lower electromagnet current being obtained to derive the necessary driving torque on the armature disc. In normal circumstances the torque derived would be proportional to the square of the primary current, and the time/current characteristics of the relay would approximate to an inverse-square law, being modified only by the effects of friction and the inertia of the moving parts. In order to give the relay a definite minimum time characteristic as required by British Standard No. 142 : 1942 (fig. 1), it is necessary to ensure that the torque developed is no longer proportional to the square of the current at higher current values. This is achieved by arranging for the upper electromagnet core to saturate at a certain primary current value, beyond which there is practically no increase in the current fed to the lower electromagnet winding.

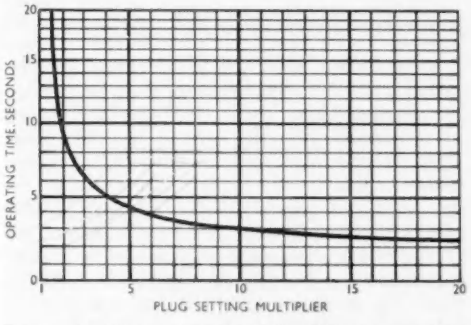


Fig. 1.—British Standard No. 142: 1942. Inverse time with definite minimum characteristic.

The disadvantages of this arrangement are as follows :

(*i*) The air gaps in the upper electromagnet, necessary for the creation of leakage flux to drive the disc, detract from its function as a transformer.

(*ii*) The reduction in iron cross-section of the electromagnet, necessary to ensure saturation, and worsened by the presence of air gaps, detracts from its function as an electromagnet.

(*iii*) The restricted winding space on the upper electromagnet worsened, by a bulky tapped primary winding, and the presence of the secondary winding result in a reduced copper cross-section with

increased copper losses and generation of heat on heavy currents.

(*iv*) Adjustment to the relay current/time curve is carried out on the assembled relay by alteration of iron circuits, rendering accurate adjustment difficult.

From these considerations it was apparent that there should be a separation of the two functions carried out by the conventional upper electromagnet, and a separate transformer was, therefore, interposed between the relay input terminals and the electromagnet windings (fig. 2).

The advantages of this arrangement are as follows :

(*i*) The transformer core may be constructed of high permeability, easily saturable material, with no large air gaps, resulting in maximum efficiency of transformation.

(*ii*) The top electromagnet may be constructed with full iron cross-section, and with full winding space used for a driving winding, without space-wasting tappings and secondary windings.

(*iii*) The dimensions of the transformer can be arranged to give adequate winding space with a copper cross-section equivalent to the secondary windings of the associated current transformers, resulting in smaller losses, and less heat generation on heavy currents.

(*iv*) Adjustment to the shape of the relay current/time curve may be carried out at the transformer stage, using direct reading instruments, with consequent saving of time and increase in accuracy. The general speed of the relay may then be adjusted at the fully assembled stage by means of the brake magnets, and only one timing of several points on the current/time curve need be carried out on each current setting of the plug bridge.

(*v*) The interposing transformer renders the relay very flexible, as only this component requires modification to give various current sizes or current/time characteristics, the electromagnets remaining the same in every case.

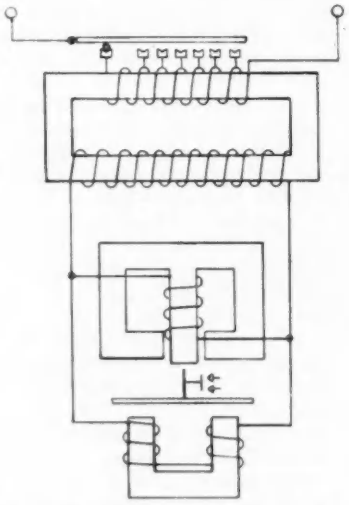


Fig. 2.—Schematic diagram of type B relay.

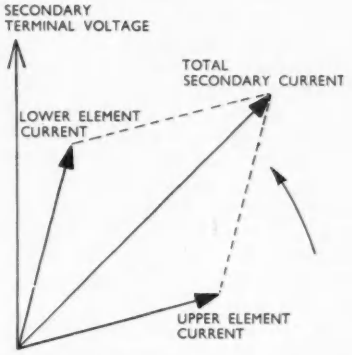


Fig. 3.—Vector diagram of electromagnet currents.

It was anticipated that the extra iron loss resulting from the additional iron volume would be very small compared with the gains made in other directions, and this has been confirmed in practice. For the same torque as a conventional pattern relay having a burden of 3·5 to 4·0 VA, the Chamberlain & Hookham Type B relay has a burden of 1·8 VA.

THE ELECTROMAGNETS.

The electromagnet system is based on that developed for maximum efficiency in the Company's kilowatt-hour metres, the main difference being in the windings. The upper electromagnet is wound with heavy gauge wire, and this, together with the construction of the core, renders the winding highly inductive, but relatively low in resistance. On the other hand, the lower electromagnet winding is highly resistive but relatively low in inductance. The impedance of the windings is balanced, to ensure equal division of current when they are connected in parallel and energised from the secondary of the interposing transformer. Maximum torque is obtained when the magnitudes of the separate currents flowing in the two windings are exactly equal. The differences in resistance and inductance of

the two windings result in a wide phase displacement between the currents in the windings and hence between the fluxes of the electromagnets, and from this displacement is derived the moving field necessary to rotate the disc. An approximate vector diagram of the currents in the electromagnet windings at fundamental frequency is shown in fig. 3.

THE INTERPOSING TRANSFORMER.

In order to obtain a particular current/time curve from the relay it is necessary to design the transformer to give a known non-linear characteristic, and an investigation has been made into the effects of winding distribution and core construction on this characteristic. The distribution of the windings comes under one of the following arrangements :

(*i*) Auto-wound. In this arrangement part of the winding is common to both primary and secondary circuits.

(*ii*) Double-wound, with internal secondary. In this arrangement the primary and secondary are electrically insulated from each other and the secondary is wound over or under the primary, on the same limb of the core.

(*iii*) Double-wound, with external secondary. In this arrangement the primary and secondary are electrically insulated from each other and the secondary is wound on a separate limb of the core from that on which the primary is wound. Leakage reactance is a maximum in this arrangement.

(*iv*) A combination of (*ii*) and (*iii*) in varying proportions.

Typical curves for each arrangement, together with a required curve are shown in fig. 4(a). In the case shown, the best choice is obviously arrangement (*iv*). Each curve has the typical shape of an A.C. magnetisation curve, but the

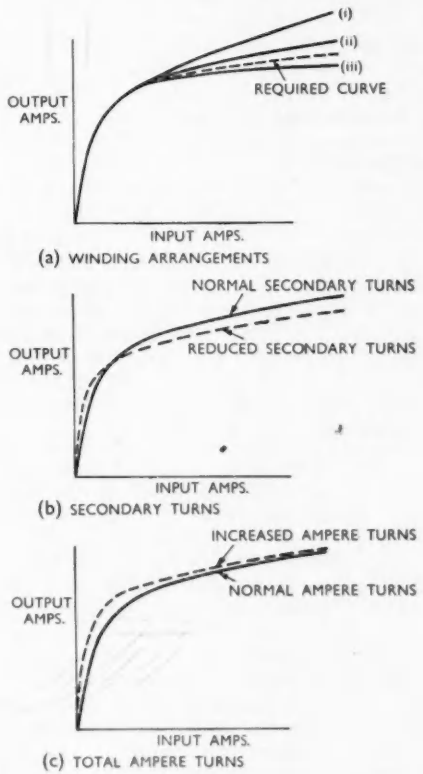


Fig. 4.—Effect of winding details on saturable transformer characteristic.

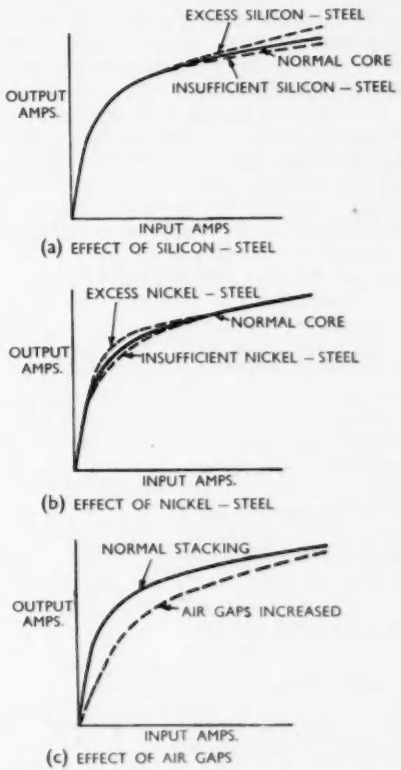


Fig. 5.—Effect of core materials on saturable transformer characteristic.

final slope at higher currents differs with each arrangement.

Arrangement (*i*) has the higher final slope, this being due to the potential difference developed across the resistance component of the common portion of the winding.

Arrangement (*iii*) has the lower final slope because the separation of primary and secondary windings on opposite limbs of the core increases the leakage reactance of the transformer to a maximum. Change in actual turns ratio has the effect of altering the secondary output in opposite senses above and below the saturation point. The transformer behaves as a current transformer below saturation, but as a voltage transformer above saturation, as shown in fig. 4(b). Alteration to the total ampere-turns has the effect of moving the knee of the curve along the horizontal axis as shown in fig. 4(c).

When the best winding arrangement has been arrived at to suit a particular required curve, it is possible to modify the curve locally by suitable choice of core material. The choice of material depends upon the characteristics required, but for one particular case it was found necessary to use a core consisting mainly of nickel-steel alloy with a small addition of silicon-steel alloy. With this as basis, the effects of increasing or decreasing one of the constituents are shown in figs. 5(a) and (b).

A further modification to the curve is possible by altering the gaps between laminations at the joints. Normal interleaving of laminations is carried out, but the amount of overlap may be varied, leaving gaps between normally abutting edges. The effects of gapping are shown in fig. 5(c) and it will be noticed that the greatest effect is on the lower part of the curve.

By selection of the winding arrangement at the design stage, and modification to the curve with change of material and slight gapping, it has been found possible to maintain a given characteristic with remarkable consistency. A range of transformers has been developed for definite minimum times of 3 seconds and 6 seconds, with current ratings of 5, 1 and 0·5 amperes, and having settings of 50-200 per cent for overcurrent relays, and 20-80 per cent, 10-70 per cent, 10-40 per cent or 5-20 per cent for earth-fault relays.

THE ARMATURE DISC.

A requirement of British Standard No. 142 : 1942 is that the relay shall reset itself to the unoperated position if the current drops to 70 per cent of the setting value. The two methods of achieving this are by gravity or by return spring.

The use of gravity as a resetting agent necessitates the employment either of extra pulleys with a cord and weight, or a horizontal main spindle of the relay. The latter requires either a cord and weight or an unbalanced member geared to the main spindle. The use of a cord and weight is deprecated on the grounds of the frail nature of the cord and the necessity for stowage arrangements for the weight during transport. Furthermore, the use of a horizontal spindle is undesirable as the reduction of friction is more difficult in horizontal bearings than in vertical bearings.

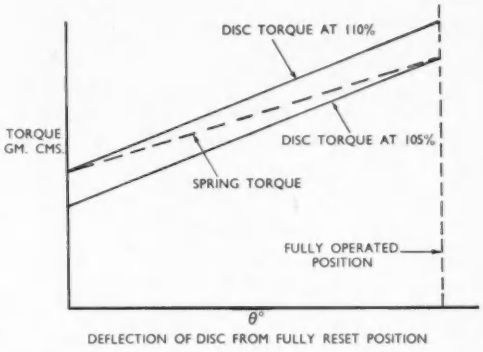


Fig. 6.—Graphical representation of correct spring setting.

The most practical form of return is by hairspring as this makes possible vertical mounting of the spindle and no special transport arrangements are necessary ; it is this form of return which has been incorporated in the type B relay.

Over a limited range the characteristic of such a return is of the form

$$T = m\theta + t \qquad (1)$$

where T = restoring torque of the spring.
m = rate of increase of spring torque per unit deflection.
θ = deflection of relay disc from the fully reset position.
t = initial torque of spring when disc is at fully reset position.

It is, therefore, necessary to ensure that the driving torque of the disc increases as the disc rotates, otherwise the relay will act as an ammeter at low currents, the disc rotating until the spring torque is equal to the driving torque. Not only would this prevent complete operation of the relay at that current, but discrimination with adjacent relays in a network would be seriously

affected by the setting up of an artificial rest position. To prevent such an occurrence, the disc has been shaped so that as it rotates the effective radius of the portion between the electromagnets increases, with a corresponding increase in driving torque..

The shape of the disc may be designed to suit the characteristic of a particular spring, but the normal manufacturing tolerances on hairsprings necessitate the inclusion of some form of adjustment to accommodate a range of hairsprings. Such an adjustment can only apply to the electromagnet system. The characteristic of the electromagnet/shaped-disc combination is of the form,

$$T' = m' \quad (\theta + \theta') \qquad (2)$$

where T' = driving torque of disc.
m' = rate of increase of disc torque per unit deflection.
θ = deflection of relay disc from fully reset position.
θ' = deflection of relay disc from an imaginary position of zero torque to the fully reset position.

from which it is apparent that m' is directly proportional to the starting torque of the relay. An adjustment, therefore, to the starting torque of the relay is a ready means whereby m' may be made slightly greater than m. In the type B relay a torque adjuster is incorporated in the lower electromagnet, consisting of a wedge-shaped piece of magnetic material which can be moved in and out of the magnetic field between the tips of the lower electromagnet by means of an adjusting screw. Total insertion of the adjuster unbalances the current division between the electromagnet windings, changes the phase difference between the two currents, and shunts the magnetic flux from the lower electromagnet. Each of these effects is in the same sense, and a reduction in torque takes place. In this manner the total change in torque brought about by movement of the adjuster from one extreme to the other is about 14 per cent. The practice adopted is to measure the rate of each spring after colletting and to log the rate of the spring fitted to each relay. If any spring is found to be outside the range of the adjustment, it is a simple matter to fit a spring of more suitable rate.

The procedure for adjusting the relay so that m' is slightly greater than m is, briefly, as follows. The true zero position of the spring is moved by rotating the hairspring collet on the armature spindle until the disc is stationary at the fully reset position with 110 per cent of the setting current flowing, i.e. t is made equal to $m'\ \theta'$ at this current. The current required to make the disc stationary in the fully operated position is then measured. If this current differs from 105 per cent of the setting current, the torque adjuster is moved in the appropriate direction, and the spring collet relocated until these two conditions do obtain. These conditions are shown graphically in fig. 6, and it will be seen that when the disc begins to rotate in either direction, it will continue to travel to the corresponding extreme position if the current remains unaltered.

THE CONTACTS.

The contact system consists of two blades, bent near the free end, terminating in platinum contacts. The bend enables alignment of the contacts to be observed from the front of the relay, a feature not embodied in other similar relays. In front of the contact blades are buffer stops against which the blades are lightly sprung. The moving contact is attached to the armature spindle by an insulating bush, and consists of a platinum rod. This bridges the two contacts already mentioned, when the armature disc reaches the operated position. The characteristic

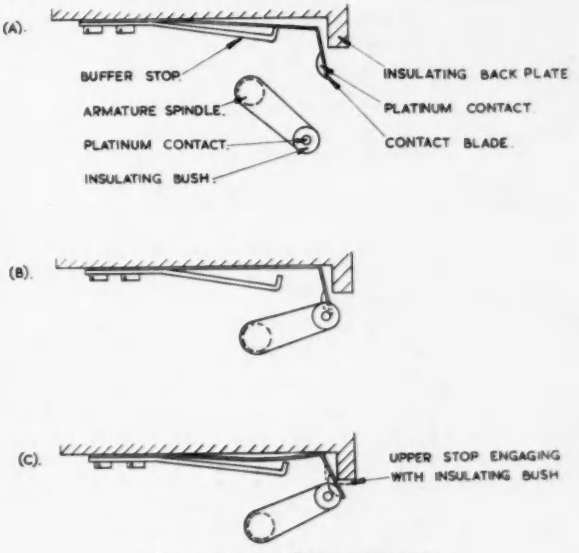


Fig. 7.—Action of tripping contacts.

properties of platinum contacts are resistance to wear and oxidation, and long experience in other applications by the Company enables great confidence to be placed in this material.

The action of the contact blades has been designed to meet all conditions of contact closure. The first part of the contact travel causes bending along the whole length of the blades, which needs little torque and hence allows contact alignment at currents only slightly in excess of the relay setting. When the blades have moved through a short distance, the point at which they are bent comes into contact with the insulating back plate, and the part of the blade between this point of contact and the anchorage of the blades begins to bow forward, having a stiffer action which prevents contact chatter on heavy overcurrents. Finally, the bush of the contact bar comes to a solid bakelite stop, and the disc is arrested. Each stage of this action is shown in fig. 7. This contact system has been found most reliable and fully meets the requirements of British Standard No 142 : 1942.

THE TRIPPING INDICATOR.

Another component part of the type B relay to which a great deal of attention has been paid, is the tripping indicator. While this performs no active part in the protection of a network, it is nevertheless important to have an indication of which relay has been instrumental in tripping a circuit breaker, as it is usual for one circuit breaker to be controlled by more than one relay.

A tripping indicator may be electrically or mechanically operated. The electrical type requires an operating current, which may be the actual tripping current. In this case the design of a universal operating coil presents great difficulty, as failure to work on low tripping currents, and burning-out on high tripping currents inevitably occur at the extreme ends of the large range of currents to be covered. On the other hand a well-designed mechanically-operated indicator requires no operating current,

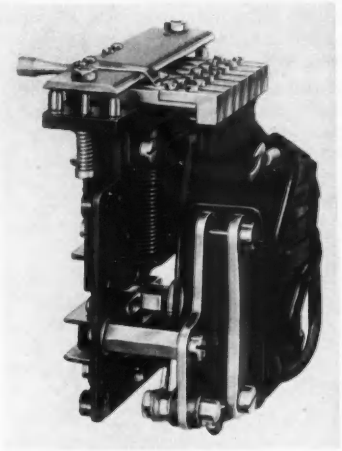


Fig. 9.—View of interposing transformer.

is independent of tripping current variation, and is positive in action. The tendency in this country is to favour the mechanically-operated indicator, and as a result of these considerations it was decided to incorporate such an indicator in the type B relay.

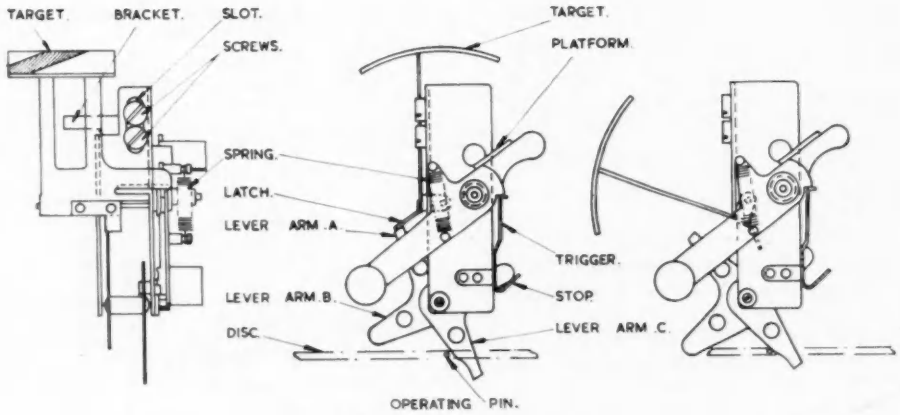


Fig. 8.—Operation of tripping indicator.

The requirements of a mechanically-operated indicator are as follows :

(*i*) The indicator must not operate until the relay is about to close the trip circuit.

(*ii*) The indicator must not be operable by vibration.

(*iii*) The indicator must be unnoticeable in the unoperated position, and prominently visible in the operated position.

(*iv*) The indicator must require very little torque for its operation.

The tripping indicator used in the type B relay is shown in fig. 8. The tripping lever is biased backwards against a stop by a very slight unbalance, and the tip of the lever arm *A* restrains the latch attached to the indicator. On top of the indicator is a target consisting of a white rectangle with a red diagonal bar. Until the disc is nearly in the fully operated position, the lever arm *B* is prevented from dropping (even if vibration is sufficiently heavy to overcome the bias) by the disc. When, however, the disc reaches the fully operated position a pin in the edge of the disc engages with lever arm *C* and rotates the tripping lever, the shape of the disc being such as no longer to restrain lever arm *B*. The only work done by the disc is in overcoming the friction of the pivots, the friction between the disc pin and the lever arm *C*, and the friction between lever arm *A* and the latch. The end of lever arm *A* is ground circumferentially about the pivot centres so that there is no tendency to raise or lower the latch when the tripping lever is rotating. The use of a thin lever and a polished stainless steel latch reduces friction at this point to a minimum. The amount of pressure exerted by the latch against the end of the lever is not great, as the indicator is only slightly unbalanced forward, the amount of unbalance increasing when the latch is released, and the indicator begins to fall. On cessation of the operating current, the disc will return to the reset position, rotating the tripping lever, which

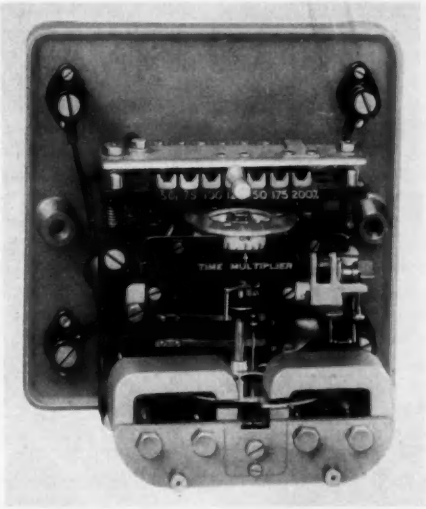


Fig. 11.—Single pole relay with cover removed.

is left quite free of the latch, to its original position. On resetting the tripping indicator, the edge of the latch runs up the curved contour of lever arm *A* which, via lever arm *B*, depresses the disc slightly until the latch is above the lever, and the latter returns to its normal position. In order to ensure no jamming in a partially reset position, the resetting mechanism consists of two parts, between which is a connecting spring. Depression of the platform extends this spring, until towards the end of the platform travel the trigger is released, the resetting arm is rapidly lifted by the spring, and the indicator is reset.

The frame of the indicator mechanism is secured to a bracket by means of two screws passing through a slot, which enables vertical adjustment of the indicator to be carried out. In the unoperated position the target is obscured by part of the relay frame, and is quite invisible from the front. In the operated position the full area of the target (·95 ins. × ·7 ins.) is visible, the curvature of the target and its close proximity to the front of the relay giving a large angle of visibility in both vertical and horizontal planes. Immediately below the target operated

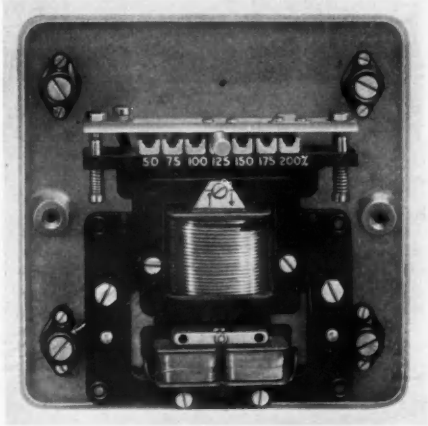


Fig. 10.—View of electromagnets.

position is a recess in the main label of the relay, where an identification card may be accommodated. In the case of multi-element relays there is also a phase-colour indicator mounted on the relay above the target, this arrangement giving trip indication, phase, and identification labels in close proximity to one another.

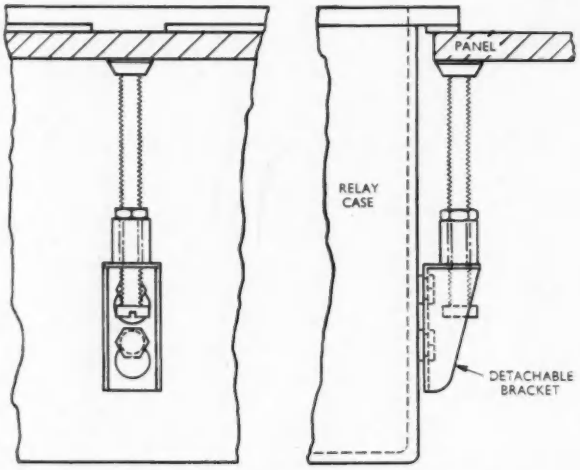


Fig. 12.—Clamping arrangement for flush pattern cases.

THE PLUG BRIDGE.

The plug bridge provides the means whereby the number of primary turns of the saturable transformer, and hence the sensitivity of the relay, may be altered. The connection lug attached to each tapping of the transformer is clamped to the rear end of a heavy channel of extruded section brass. The seven channels are attached to the support board of insulating material on the front edge of which is engraved the setting value appropriate to each channel. The common connection strip is supported over the channels, under spring tension, and the insertion of the heavily silver-plated plug in any channel makes excellent connection between that channel and the common connection strip. When the plug is withdrawn, the highest setting is automatically selected, ensuring that in no circumstances can the main C.T. be open-circuited. The plug may be removed or inserted into the required channel by hand, and no screwdriver or special tool is necessary.

THE BRAKE MAGNETS.

The braking element consists of two D-shaped permanent magnets of 35 per cent cobalt-steel alloy. Owing to the high coercive force of this steel, permanence and stability of calibration are assured, even when the relay is subjected to the excessive demagnetising forces resulting from heavy overcurrents. The magnets are carried between two stout brass plates and form a unit which is bolted to the main relay frame. Each pair of magnets is magnetised simultaneously to ensure opposite polarity. A magnetic shunt located between the magnet poles below the disc can be moved in and out by means of a micrometer screw. Insertion of the magnetic shunt decreases the magnetic flux passing through the disc, with a consequent increase in relay speed. This adjustment is used to set the operating time of the relay at one point on the current time curve, all other points following in accordance with the calibration of the interposing transformer.

GENERAL ARRANGEMENT.

The component parts discussed in detail above are compactly assembled together in such a manner as to give complete accessibility during periodic examinations. A die-cast frame in aluminium carries the disc with its associated top and bottom bearings, the fixed contacts, tripping indicator, and the brake magnets. If any examination of the moving parts is necessary this may be done by withdrawing the four corner fixing screws which secure the frame to a back plate, and disconnecting the trip leads. Recali-

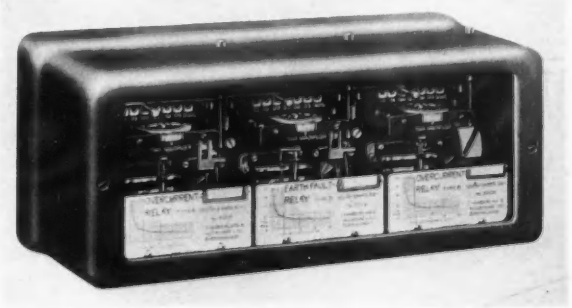


Fig. 13.—Three-element horizontal projecting pattern case.

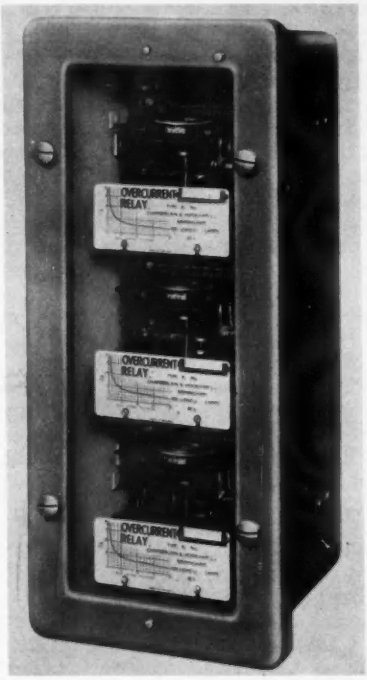


Fig. 14.—Three-element vertical flush pattern case.

bration is unnecessary after this removal and replacement, as the frame is accurately located on the back plate by the fixing screws. The transformer and plug bridge are mounted behind the back plate, which also carries the electromagnets (see figs. 9 and 10). A view of a single-element relay with the cover removed is shown in fig. 11.

CASES.

Type B relays are available in single, double, and triple pole units, in projecting or flush pattern cast aluminium cases. The double and triple pole units may be arranged for horizontal or vertical mounting.

The bases on which the relays are mounted are common to both flush and projecting patterns. In the case of the projecting pattern only the four corners of the base touch the panel, the rest of the periphery being undercut so as not to provide a ledge for dust, etc., to accumulate.

The projecting type covers are of smooth streamlined appearance, the only protrusions being the resetting buttons and cover fixing nuts, which latter are knurled and provided with wide slots into which a coin may be inserted, in lieu of a screwdriver. The cover extends to within a small distance of the panel, ensuring that its removal does not cause dust to fall into the movement.

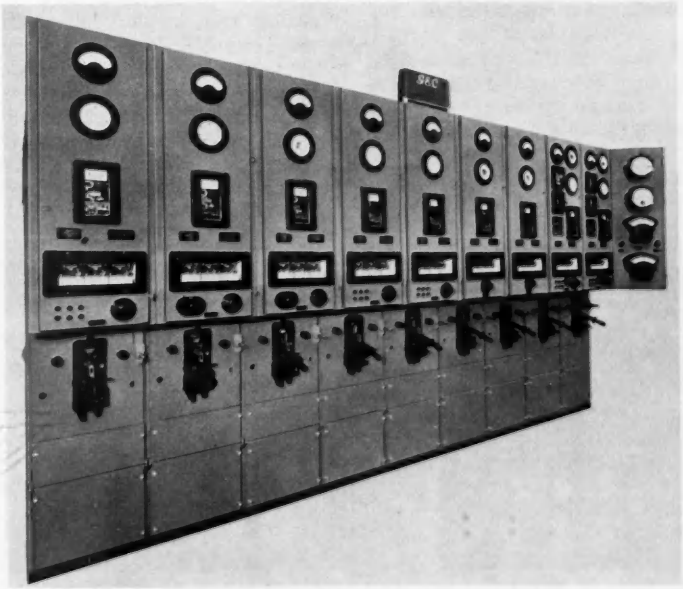


Fig. 15.—View of a typical installation of type B relays.

The flush pattern covers consist of two parts. The one part is an open-ended box which screws to the base in place of the normal projecting pattern cover, and has a flange around its outer edge. Detachable clamps are fitted to the sides

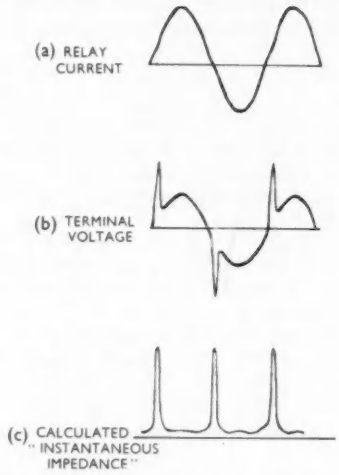


Fig. 16.—Waveforms for type B relay under sinusoidal current conditions.

of the box, in positions corresponding to raised bosses on the underside of the flange, for attaching the box to the panel, as shown in fig. 12. The second part of the cover carries the window, and is attached to the flange by captive knurled screws which are also provided with wide slots into which a coin may be inserted, in lieu of a screwdriver. The external appearance is again smooth and pleasing, the only protrusions being the resetting buttons and cover fixing screws. Typical examples of cases are shown in figs. 13 and 14, and a view of a panel incorporating type B relays is shown in fig. 15.

EFFECTS OF EXTERNAL CONDITIONS.

External conditions which affect the performance of relays include applied current waveform, frequency and temperature.

The non-linear property of any saturable relay gives rise to distorted voltage waveforms across the terminals when sinusoidal current is flowing. At heavy currents the voltage waveform consists of a sinusoidal base (due to winding resistance) together with an additional sharp pulse occurring during the brief parts of the cycle in which the core passes from saturation in one direction to saturation in the other. It is possible by comparison of current and voltage waveforms to assess the " instantaneous impedance " of the relay, and fig. 16 shows input current, terminal voltage and " instantaneous impedance " waveforms for a type B relay at a current equal to 20 times the setting.

When testing saturable relays the usual method is to apply a sinusoidal voltage across a circuit containing the relay and a linear impedance in series. If this impedance exceeds four times the unsaturated impedance of the relay the change in " instantaneous impedance " of the relay is small compared with the total impedance of the circuit and the current flowing will be very nearly sinusoidal. If, however, the ballast impedance is reduced to too low a value the " instantaneous impedance " of the relay governs the amount of current flowing and results in a distorted current waveform. The waveforms of current and terminal voltage for a relay under these conditions are shown in fig. 17. Speeding up or slowing down of a relay due to distorted current waveform depends upon whether the waveform has a peak or depression at the parts of the cycle corresponding to the peaks in the relay voltage waveform. Thus the effect of current waveforms similar to that shown in

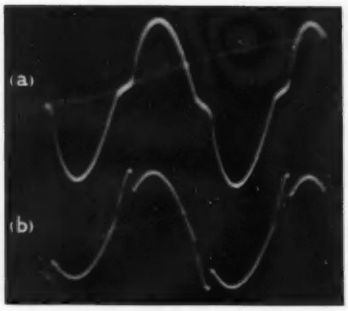


Fig. 17.—Waveforms for type B relay under non-sinusoidal current conditions.

Fig. 18.—Output voltage waveform of interposing transformer.

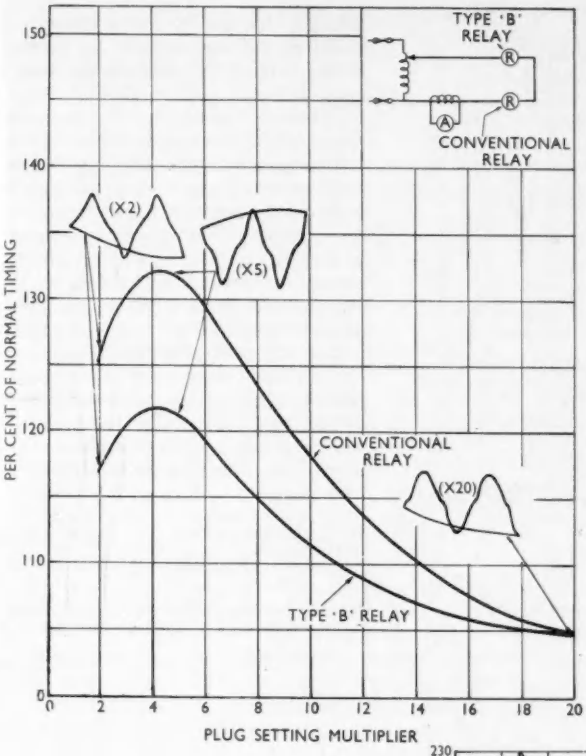
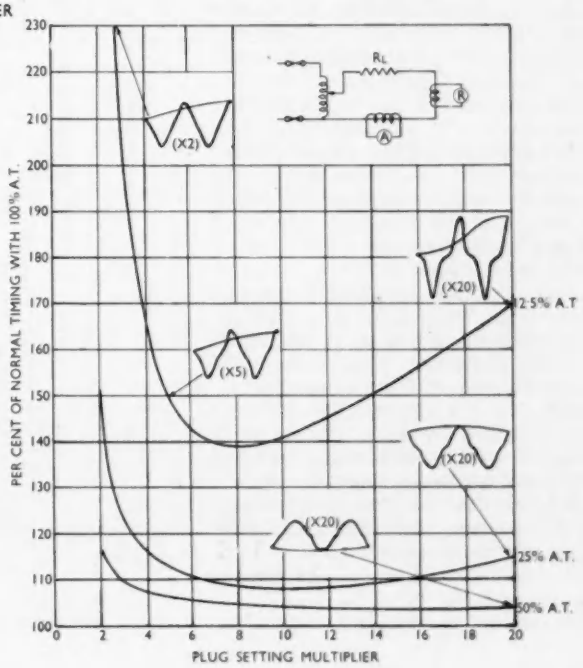


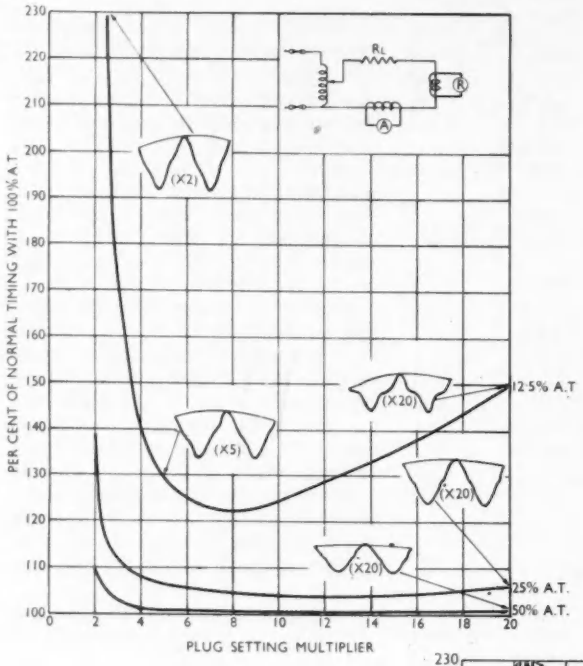
Fig. 19 (*above*).—Effect of distorted current waveforms on relay operating times.

Fig. 20 (*below*).—Effect of current transformer ampere-turns on conventional pattern relay operating times.

fig. 17 is to slow down the relay, and, in general, it may be stated that if the current waveform distortion can be directly attributed to the influence of a saturable relay "instantaneous impedance" the relay will be slowed down. In the case of the type B relay, however, this effect is reduced by the use of the interposing transformer which saturates completely, giving output waveforms of voltage and current which are largely independent of the input current waveform. The output voltage waveform of the transformer for sinusoidal input current equal to 20 times the setting is shown in fig. 18. The resulting superior performance of the type B relay under conditions of distorted current waveform is demonstrated by the curves shown in fig. 19, which were obtained from a circuit consisting of a variable sinusoidal voltage source feeding a conventional pattern relay of recent design, a type B relay, and an ammeter (with current transformer) in series, no linear impedance being deliberately included. The timing curves obtained under these conditions are expressed as a percentage of timing curves separately obtained on each of the relays with sinusoidal current flowing. Current waveforms at various points on these curves are also shown. The effect of distorted current waveform is markedly less on the type B relay than on the conventional pattern relay.

Another circumstance in which distorted current waveform may occur is in a protective scheme where main current transformers of insufficient capacity have been used. Reference has already been made above to the nature of the voltage waveform across saturable relays under heavy current conditions, particular emphasis being laid on the sharp pulses occurring every half cycle. Normal forms of voltmeter are little affected by these pulses, and



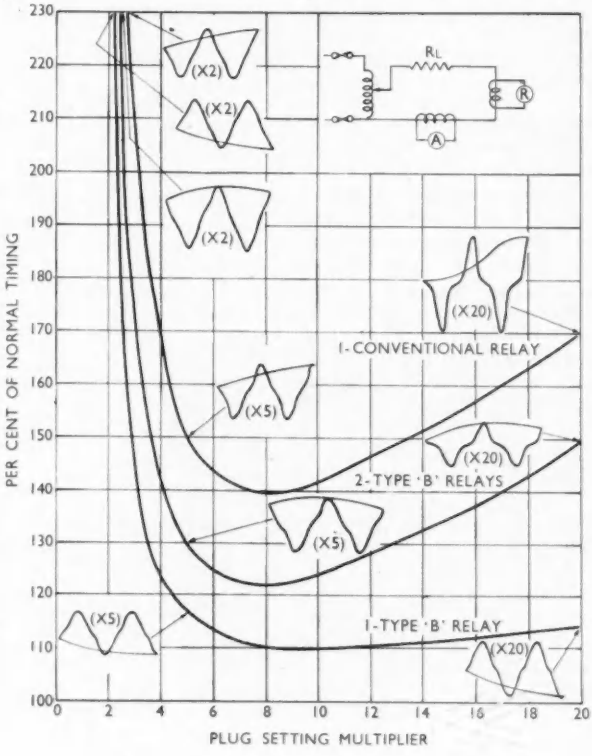


referred to its C.T. primary was taken as 100 per cent at all current values. The C.T. ampere turns were then reduced to 50 per cent, 25 per cent and 12·5 per cent of normal, and the timing curves under these conditions expressed as a percentage of the basic curve. Relay current waveforms at various points on these curves are also shown. Fig. 21 shows similar curves obtained when two type B relays in series were substituted for the conventional pattern relay. The combined burden of these relays was within 5 per cent of that of the conventional pattern relay, and the C.T. could be considered as operating under similar conditions. The considerable errors shown in each case are partly due to the large inherent ratio errors of the C.T.,

Fig. 21 (*above*).—Effect of current transformer ampere-turns on type B relay operating times.

Fig. 22 (*below*).—Effect of current transformer capacity on relay operating times.

VA burdens calculated from the product of voltmeter and ammeter readings approach closely to watt-loss figures at heavy currents. This state of affairs often gives rise to the mistaken impression that the burden on the main C.T. increases rather less than in proportion to the square of the current, and that C.T.'s which would not otherwise maintain ratio at heavy currents, are therefore rendered usable. Consideration of the relay terminal voltage waveform does, however, indicate that for the duration of the pulse, the main C.T. must develop sufficient voltage to meet the peak, i.e. must have almost the same output as if the relay had not become saturated. The effect of main C.T. capacity is illustrated by fig. 20, the circuit consisting of a variable sinusoidal voltage source, a series resistance R_L, an ammeter (with current transformer) and a current transformer of adequate capacity feeding a conventional pattern relay of recent design. The timing curve with R_L equal to four times the unsaturated impedance of the relay



which errors are difficult to assess in view of the non-sinusoidal secondary current. An indication of this effect is given in fig. 22 which shows the timing curves at 12·5 per cent of normal ampere turns expressed as a percentage of the timing curves at 100 per cent of normal ampere turns, for the conventional pattern relay, two type B relays in series, and one type B relay only, respectively, using the same C.T. Again the interposing transformer in the type B relay is advantageous in reducing the effect of main C.T. saturation on the timing curve of the relay, and if the reduced VA burden is also taken into account, the effect of reduced C.T. capacity is much less in the case of the type B relay than in the conventional pattern.

Analytically, the phase displacement and magnitude of higher order harmonics, rather than their frequency, determine whether the relay will be slowed down or speeded up. If, however, sinusoidal current is maintained, and the frequency varies, the tendency is always for the relay speed to increase with increase in frequency. This result is due to the increased sweeping rate of the moving field of the electromagnets more than overcoming the effect of decreased current in the electromagnets caused by the increase of impedance with frequency. Typical current time curves for the type B relay at different frequencies are shown in fig. 23.

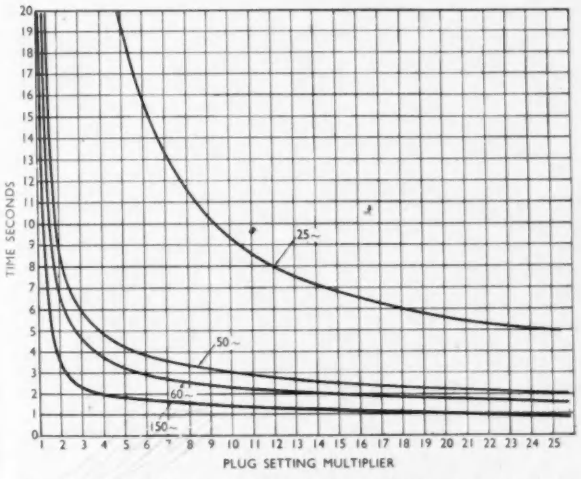


Fig. 23.—Effect of frequency change on type B relay operating times.

Increase in temperature causes an increase in resistance of the transformer secondary winding and also of the two electromagnet windings, the latter disturbing the equality of impedance, and current division. The overall effect is a slowing down of the relay with increase in temperature, as shown in fig. 24.

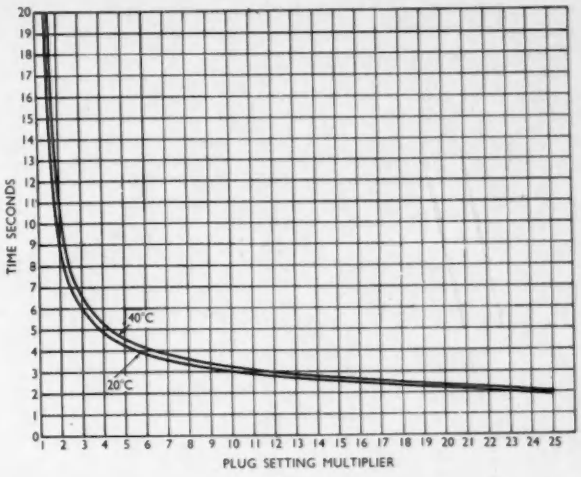


Fig. 24.—Effect of temperature change on type B relay operating times.

CONCLUSION.

The separation of the functions of saturable transformer and upper electromagnet in the type B relay offers great advantages. For the same torque as the conventional pattern relay, the VA burden is halved, relieving current transformer design problems. The complete saturation of the small interposing transformer results in an output waveform which is largely independent of input current waveform and greatly reduces the effect of distorted current waveform on the discrimination of the relay. These advantages constitute an important advance in the art of relay design.

TECHNICAL LITERATURE

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS, BY MEMBERS OF THE G.E.C. AND ITS ASSOCIATED COMPANIES.

LIGHTNING PROTECTION OF ELECTRICAL TRANSMISSION SYSTEMS

By C. J. O. Garrard (Witton Engineering Works).

The Engineer, July 28th, 1950.

A review of some recent papers on lightning and lightning protection is followed by suggestions for a systematic study of different types of protection by practical tests in distribution networks.

PRESENT-DAY PRACTICE IN ELECTRICAL SWITCHGEAR

By C. J. O. Garrard (Witton Engineering Works).

Engineering, September 15th, 1950.

A brief account of the evolution of electricity supply in Great Britain and in the countries to which British switchgear is likely to be exported, and a review of the more recent developments in switchgear design, lead to some considerations on present practice and probable future development of switchgear and protective gear.

THE CASE FOR THE OIL-MODIFIED SYNTHETIC RESIN VARNISH

By R. H. Robinson (Witton Engineering Works).

Electrical Industries, October, 1950.

The paper discusses the properties of oil-modified synthetic resin varnishes and compares them with the oleo-resinous types which were used for the impregnation of electrical windings up to recent times. Curves are given showing the behaviour of stators wound with synthetic enamelled wire and impregnated in the two types of varnish when tested in " cold-wet" and tropical atmospheres.

THE INDUSTRIAL APPLICATIONS OF GAS-FILLED TRIODES (THYRATRONS)

By R. C. Walker (Osram Valve Department).

Chapman & Hall. 40s. Pp. 325.

This book deals primarily with the hot cathode grid-controlled gas-filled triode (thyratron) and gives a detailed but easily understood summary of the operating characteristics and physical theory of this and allied valves.

Methods of control in basic circuits by grid amplitude or phase change are treated extensively and considerable space is devoted to industrial applications involving impulse and phase-controlled circuits, voltage and current regulators, etc. Other devices included are cold-cathode triodes, ignitrons and gas discharge photoflash lamps. There is also an extensive bibliography.

THE FLOW OF GLASS (393)*

By R. W. Douglas (Research Laboratories).

Trans. Soc. Glass Techn., Vol. 33, Pp. 133-162 (1949).

The variation of the viscosity of associated liquids and glasses with temperature cannot be expressed by the same law as that relating to normal liquids. A variable, which is a function of the atomic configuration and hence of temperature, must be introduced. When this is done, a satisfactory account can be given of the difference in behaviour of the two types of liquid. A full expression for the coefficient of viscosity as a function of temperature for associated liquids is derived. The theory is applied in discussing the published data on the viscosity of glass, which may be regarded as a special type of associated liquid.

AIR-COOLED HIGH INTENSITY HIGH PRESSURE MERCURY VAPOUR LAMPS (403).*

By V. J. Francis (Research Laboratories).

Trans. Ill. Eng. Soc. (London), Vol. 15, No. 9 (1950).

During and since the war there have been important developments in high pressure mercury vapour lamps. As a result much more is now known of the properties of lamps with high power loading per centimetre of arc than was the case ten years ago. As well as significant progress with small source high brightness lamps proper, there has emerged intermediate between these and the older tubular lamps a design of lamp with luminous efficiencies greater than those previously obtainable. Useful progress has been made also with the colour-rendering properties and new applications are in consequence being found.

REFRACTIVE - INDEX MEASUREMENTS AS A CONTROL OF THE QUALITY OF LEAD GLASS FOR TUBING MANUFACTURE (420).*

By M. Manners and J. H. Partridge (Research Laboratories).

Trans. Soc. Glass Techn., Vol. 33, Pp. 59-63 (1949).

Refractive - index measurements have proved a satisfactory method of assessing the variability in glass quality and have been used to test the efficiency of batch mixing in a controlled experiment.

A PORTABLE GEIGER COUNTER (426).*

By M. Michaelis and R. O. Jenkins (Research Laboratories).

Electronic Engineering, March, 1950.

Recent years have seen a considerable extension in the use of radioactive substances and installations producing ionising radiations. The need has therefore become apparent for equipment to measure the intensity of such radiations. The design of the apparatus described is aimed at a simple and compact instrument, relatively cheap to manufacture, for use in rough comparative assays and in general radiation surveys. The latter application is of particular importance in assessing the protection necessary for personnel against ionising radiation.

THE EXACT SOLUTION FOR TRANSIENT DISTORTION IN NETWORKS (427).*

By D. C. Espley (Research Laboratories).

Electronic Engineering, March, 1950.

A rigorous and systematic method of distortion correction in electrical networks is presented. The correction network is derived by inversion from a hypothetical simulating network, which can be defined exactly and systematically from the waveform of distortion of the actual transmission system.

SPECTRAL CHARACTERISTICS OF LIGHT SOURCES FOR FADING AND DEGRADATION TESTING (430).*

By B. S. Cooper and F. S. Hawkins (Research Laboratories).

Proceedings of Symposium " Photochemistry in Relation to Textiles," Society of Dyers and Colourists, Harrogate, September, 1949.

The spectral distribution of energy in the visible and ultra-violet regions has been measured for the enclosed carbon arc commonly employed in fading test apparatus. Tests have been made on both D.C. and A.C. arcs, and the effect of electrical loading, asymmetrical polar distribution, and obscuration of the enclosing globe has been investigated. Certain data are also presented for the high-intensity carbon arc and for three types of metal-vapour electric discharge lamp likely to be suitable for photochemical work. Comparison is made with incandescent tungsten sources and with sunlight for corresponding spectral regions.

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